AD-A061 319 NAVAL RESEARCH LAB WASHINGTON D C SHOCK AND VIBRATIO--ETC F/G 20/11
THE SHOCK AND VIBRATION DIGEST. VOLUME 10, NUMBER 9.(U)
SEP 78

UNCLASSIFIED

NL

1 OF 1
AD
A061319

END
DATE
FILMED
1 -79
DDC

AD A0

DD

THE SHOCK AND VIBRAT
DIGEST. Volu

Number 9.

A PUBLICATION OF
THE SHOCK AND VIBRATION
INFORMATION CENTER
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C.

11 Sep 78

FOR RECORD AND ANNOUNCEMENT ONLY

THE SHOCK AND VIBRATION DIGEST

Volume 10 No. 9
September 1978

STAFF

The Shock and Vibration Digest is a monthly publication of the Shock and Vibration Information Center. The goal of the Digest is to provide efficient transfer of sound, shock, and vibration technology among researchers and practicing engineers. [illegible]

[illegible]

[illegible]

[illegible]

A publication of

THE SHOCK AND VIBRATION INFORMATION CENTER

Code 8404 Naval Research Laboratory
Washington, D.C. 20375

Henry C. Pusey
Director

Rudolph H. Volin

J. Gordon Showalter

Barbara Szymanski

Carol Healey

CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

AFIPS: American Federation of Information Processing Societies
210 Summit Ave., Montvale, NJ 07645

AGMA: American Gear Manufacturers Association
1330 Mass. Ave., N.W.
Washington, D.C.

AHS: American Helicopter Society
1325 18 St. N.W.
Washington, D.C. 20036

AIAA: American Institute of Aeronautics and Astronautics, 1290 Sixth Ave.
New York, NY 10019

AIChE: American Institute of Chemical Engineers
345 E. 47th St.
New York, NY 10017

AREA: American Railway Engineering Association
59 E. Van Buren St.
Chicago, IL 60605

[illegible]: [illegible]
[illegible]
New York, NY [illegible]

ARPA: Advanced Research Projects Agency

[illegible]: [illegible]
[illegible]
New York, NY [illegible]

[illegible]

ICF: International Congress on Fracture
Tohoku Univ.
Sendai, Japan

IEEE: Institute of Electrical and Electronics Engineers
345 E. 47th St.
New York, NY 10017

IES: Institute of Environmental Sciences
940 E. Northwest Highway
Mt. Prospect, IL 60056

IFToMM: International Federation for Theory of Machines and Mechanisms, US Council for TMM, c/o Univ. Mass., Dept. ME
Amherst, MA 01002

INCE: Institute of Noise Control Engineering
P.O. Box 3206, Arlington Branch
Poughkeepsie, NY 12603

ISA: Instrument Society of America
400 Stanwix St.
Pittsburgh, PA 15222

ONR: Office of Naval Research
Code 474, Dept. Navy
Arlington, VA 22217

[illegible]

DIRECTOR NOTES

This issue contains the Advance Program for the 49th Shock and Vibration Symposium. My most sincere thanks are extended to the program committee for a job well done. In my opinion, the selection of technical papers this year promises to be as interesting and informative as any we have ever had. The National Aeronautics and Space Administration takes its turn as host with Goddard Space Flight Center doing the honors. The outstanding cooperation and support by Brian Keegan and others at the Goddard has made our job at SVIC substantially easier.

In the Opening Session, the Keynote Address and two of the invited papers will be presented from the viewpoint of NASA interests. As always, it is expected that these talks will provide useful information to a broad segment of the technical community and inspiration for fruitful discussions during the remainder of the symposium. We will also be treated to a veiw from the Department of Defense with respect to dynamics and the DoD technology thrusts. The speaker recently came to DoD from the Aerospace Corporation, so we may anticipate that dynamics problems are not exactly new to him.

I am proud to announce that, for the first time in several years, there is a complete session in the program covering human response to vibration and shock. This session was especially organized, rather late I might add, to meet a special need. The program committee, and others, felt there should be more interchange of information between the biodynamics people and those concerned with structures and equipment. My thanks to Dr. John Guignard for his assistance in organizing the session and to the speakers for accepting our invitation to participate. I think that representatives from all areas of the shock and vibration fraternity will be interested to hear these papers. We look forward to a successful symposium.

H.C.P.

EDITORS RATTLE SPACE

THE BLACK BOX SYNDROME

Many engineers seem to be relying on data processing devices but apparently do not understand how they work. It has become common practice for both mathematical analysts and experimentalists to enter data into "black boxes" that manipulate or process the data. Engineering judgments and recommendations are therefore increasingly based on the results of some sort of data manipulation process that isn't understood by the user -- I call it the "black box syndrome." The black box might be a large general purpose computer program for the mathematical analyst or a real time analyzer for the experimentalist. Regardless, this practice frightens me because important decisions are being made on data processed in ignorance -- the user does not know the capabilities of assumptions, compromises, or limitations of the system he's depending on. At the very least the user fails to take full advantage of the capability of the device; even worse, ignorance can result in errors in judgment that may in turn lead to an engineering disaster.

Some years ago the technologies of both experimentation and mathematical analysis, based on electronics, began to grow at a rapid rate. At present the digital computer and other portable digital data processing devices are marvelous data processing tools, capable of turning out accurate results quickly. The large data processing and storage capabilities of digital computers have made practical the solution by numerical methods of complex structural dynamics problems at a reasonable cost. As a result the capability and cost effectiveness of the engineer has grown at a phenomenal rate. In the experimental area new measuring devices have allowed voluminous amounts of data to be collected in a precise manner. Coupled with this data gathering capability has been tremendous growth in the ability to analyze complex signals instantaneously with the real-time analyzer.

The problem as I see it today is that the capabilities of hardware and software have grown much faster than those of the average engineers who use them -- thus bringing on the black box syndrome. As a result, either the engineer is totally unfamiliar with the capabilities of digital data processing and therefore does not derive full benefit from their application or he uses them even though he is only partly familiar with their capabilities and limitations. Data in and data out thus equal a decision, and only a few engineers know why, and only a few are aware that the black box can distort, has limits, and can degrade results.

The solution to this dilemma is training. Good training is available (see the monthly Digest short course listings) at a reasonable cost -- a fraction of the cost of the equipment. In fact, most companies that make black boxes are eager to train users. The vendors realize that the more the buyer knows about their black box, the more he will use it and that this is a good way to establish a demand for larger and better black boxes. Training courses increase the capability of the engineer, as well as his confidence that the decisions made are based on facts rather than on magically manipulated data. I recommend that management provide training opportunities for their engineers before they begin to use new equipment. In this way the risks inherent in the black box syndrome can be avoided.

R.L.E.

BALANCING MACHINES REVIEWED

D.G. Stadelbauer*

Abstract - This article reviews the history of balancing machines and compares various types currently in use.

Computerized balancing has been carried out for years in large, high-speed test facilities for flexible turbine rotors and generator rotors. With the advent of the low-cost table-top computer, a similar approach has become economical for many production balancing operations, and the first such installations are underway (see Fig. 1 for a typical arrangement). Thus, the art of balancing has become a precisely controlled routine, and all steps and salient data are permanently recorded.

EARLY BALANCING MACHINES

The first balancing machines were developed around 1900; they were trial and error devices consisting of a flexibly mounted set of bearings with some means of drive (see Fig. 2). Years passed before mechanical indicators were developed. First the magnitude of vibration was indicated; then the high spot on the shaft was used as a crude reference for the angular position of unbalance.

During the late 1920s and early 1930s elaborate counter vibration mechanisms were developed that could counteract the unbalance vibration in the balancing machine by means of a mechanically generated counterforce of known magnitude and phase angle. During the 1940s, electrical indicating systems with electromagnetic pickups and phase reference generators became available; the latter rotated in synchrony with the workpiece. In response, mechanical plane selectors and nodal bars were added to older style compensation machines to allow a direct readout of unbalance in the correction planes during the first spinup.

On a typical compensation machine (see Fig. 3) the workpiece (1) was end driven from a faceplate (2) and rotated on open rollers (3) suspended from adjustable springs (4) via a linkage (5). The motor-driven faceplate also drove a cam (6) via a manually turned differential (7). The latter served to change the angular relationship between cam and workpiece. A vertical pin (8) transmitted the motion of the cam into the countervibration mechanism (9). The amplitude picked up by the axially moveable finger (10) was transferred along the machine bed by an oscillating shaft (11) and fed back through counter springs (12) into the support linkage. By

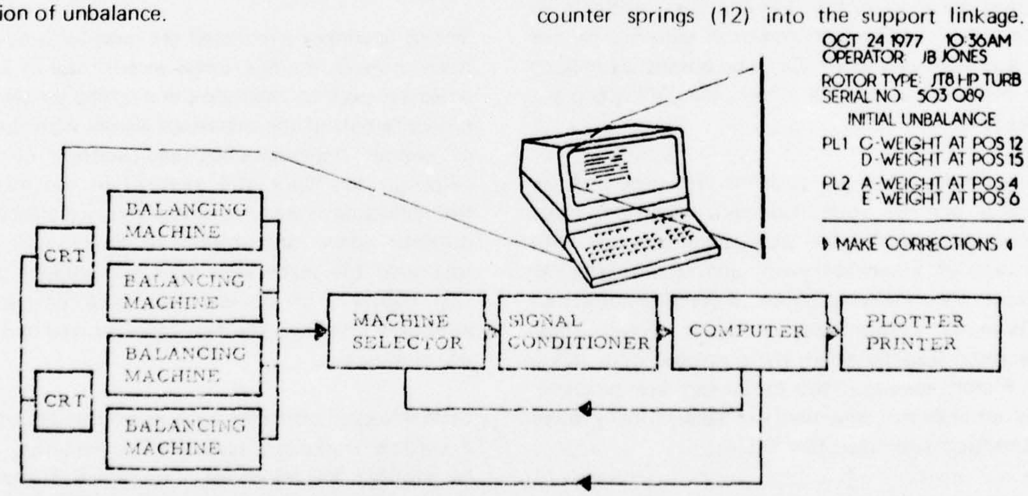


Figure 1. Typical Computer Control of Several Balancing Machines

*Executive Vice President, Schenck Trebel Corporation, Deer Park, Long Island, NY 11729

United States Patent Office.

HENRY MARTINSON, OF HAWKSVILLE, CANADA.

Letters Patent No. 110,260, dated December 20, 1870.

IMPROVEMENT IN THE MODE OF BALANCING SHAFTS.

The Schedule referred to in these Letters Patent and making part of the same.

To all whom it may concern:

Be it known that I, HENRY MARTINSON, of Waterloo, in the Province of Ontario and Dominion of Canada, have invented a new and improved Balance for Shafting, Cylinders, &c.; and I do hereby declare that the following is a full, clear, and exact description thereof, which will enable others skilled in the art to make and use the same, reference being had to the accompanying drawing forming part of this specification, in which—

Figure 1 represents a plan view, partly in section, of my invention.

Figure 2 is a transverse section of the same, *x x* being the section-line.

Similar letters of reference indicate corresponding parts.

This invention has for its object so to hang and balance shafting, drums, cylinders, and other rotary machinery, that the same may be properly tested while running, to ascertain whether the center of gravity is properly distributed along their axes.

The chief difficulty hitherto experienced in balancing cylindrical rotary bodies consists in the disproportionate heaviness at the opposite ends of the cylinder, the balancing of one end leaving the other end, and thereby the entire body, usually as inaccurate as though not at all balanced.

My invention overcomes this difficulty by providing for the simultaneous balancing of both ends, and thereby the entire body of the cylinder.

My invention consists in the application of yielding bearings for both ends of the cylindrical body to be balanced, and in the connection therewith of a jointed driving-shaft, which will allow the adjustment and oscillation of the driven end of said cylinder.

a a are the journal-boxes or bearings for the two ends of the shaft A, that carries the cylinder or drum B, or other heavy rotating device to be tested.

Each of said bearings or boxes *a* is arranged between four, more or less, springs or cushions, C C.

These springs are made of coiled metal, or other suitable material, and are secured in the stationary frame D, and disposed around the bearings to evenly balance the same between them.

The drum, cylinder, or other weight on the shaft, will, if unevenly balanced or weighted, so as to be heavier on one side than on the other, at one or both ends, cause the oscillating movement of the said cylinder in and with its bearings, the springs yielding to such motion.

The amount of oscillation can be readily ascertained at either end by a pencil, chalk, or other marker, and the balance adjusted in accordance with such marks.

The shaft A is, by universal joints *b b*, connected with the driving-shaft E, whereby that end of the cylinder to which the power is applied will be allowed to swing as well as its other end.

Having thus described my invention,

I claim as new and desire to secure by Letters Patent—

The balance for cylindrical bodies, composed of the springs C C and bearings *a a*, and combined with the jointed driving-shaft, substantially as herein shown and described.

HENRY MARTINSON.

Witnesses:
WILLIAM BROCK,
J. HUGHES.

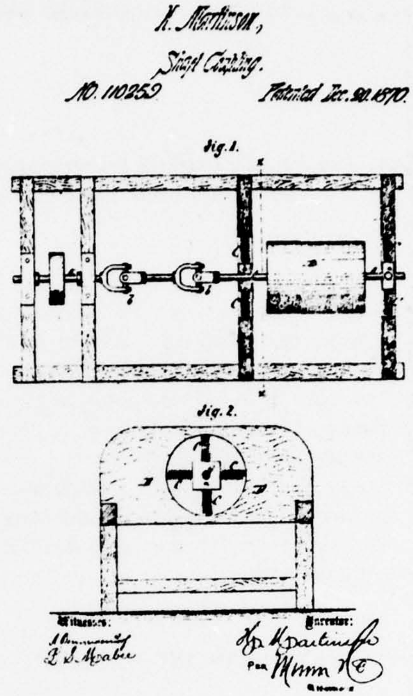


Figure 2. First Known American Patent on a Balancing Machine

adjusting the phase angle and amplitude of counter-vibration until a dial indicator (13) attached to each linkage registered zero the angle of unbalance could be read on a protractor (14) and the quantity on a scale (15). Readings were taken in sequence for the left and right correction planes by alternately locking out the other plane with a nodal bar (16) and plane locks (17).

The manufacturers of machines with electrical indicating systems countered with electrical plane separation networks that enabled the operator, with the help of a balanced rotor and test weights, to calibrate the indicating system in practical correction units in any two selected correction planes. Angle indication was provided by a stroboscopic lamp, which eliminated the need for an end-drive coupling. This development was used to balance many small and medium size rotors (see Fig. 4).

During the 1950s competition continued, and both types of machines were further refined. An electronic null indicating system replaced the dial indicators on compensating machines, and electrical machines were equipped with an initial unbalance compensating network called a compensator (see Fig. 5).

The compensator eliminated the need for a balanced rotor. Instead, the first (unbalanced) rotor of a series could be used to calibrate the machine by electrical compensation of the unbalance signals with the help of several potentiometers and suitable circuitry. Although the rotor still vibrated in the machine, the indicating system registered zero unbalance. The operator added test weights of known value and calibrated the plane separation and amount indication networks of the machine. Thus the need for physically balancing the first rotor by trial and error was eliminated.

Compensation machines were usually equipped with a tunable workpiece suspension system that could be adjusted for resonance. This provided good sensitivity. Machines with electrical indication, however, had non-tunable, softly sprung suspensions in which the workpiece rotated considerably above resonance.

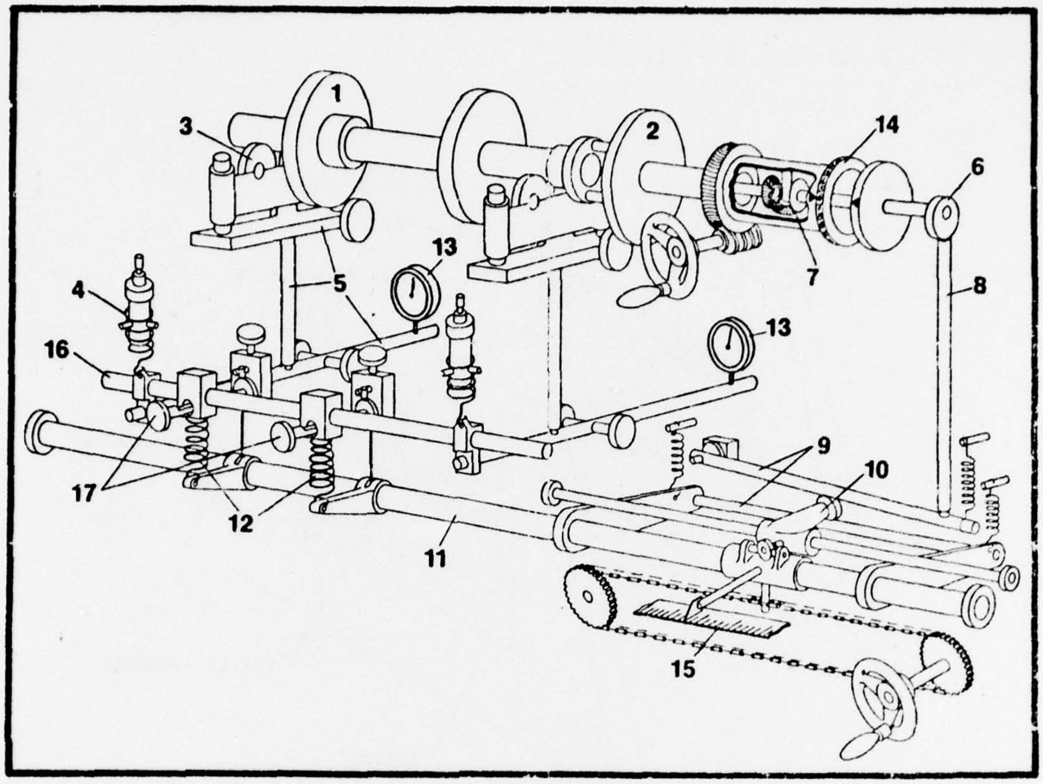


Figure 3. Schematic of Compensation Machine with Counter Vibration Mechanism

Hence, their later designation as soft-bearing balancing machines.

HARD-BEARING MACHINES

In the late 1950s and early 1960s a new approach to balancing was developed: the hard-bearing machine (see Fig. 6). The workpiece rotates in rigidly supported bearings, and unbalance is measured directly as centrifugal force. Various types of pick-ups are used. A serious problem was the extremely low signal to noise ratio, which necessitated expensive filtering systems so that adequate sensitivity at balancing speeds low enough for common shop use could be obtained. The first machines were over-designed with regard to structure; this assured ample rigidity but added to their cost.

The first hard-bearing machines were thus expensive to buy and to maintain. Significantly more electronic components were needed than for the soft-bearing machine. After several years of refinement and the advent of solid state components and plug-in circuit boards, the hard-bearing machine became more competitive pricewise; the superiority of the system soon propelled it to the forefront of the market.

One significant advantage is permanent calibration. This feature, defined by ISO 1940, "provides calibration for any rotor within the capacity and speed range of the machine by 'setting' it." Setting, in turn, is defined as "the operation of entering into the machine information concerning the location of the correction planes, the location of the bearings, the radii of correction, and the speed, if applicable."

The centrifugal force exerted by a specific amount

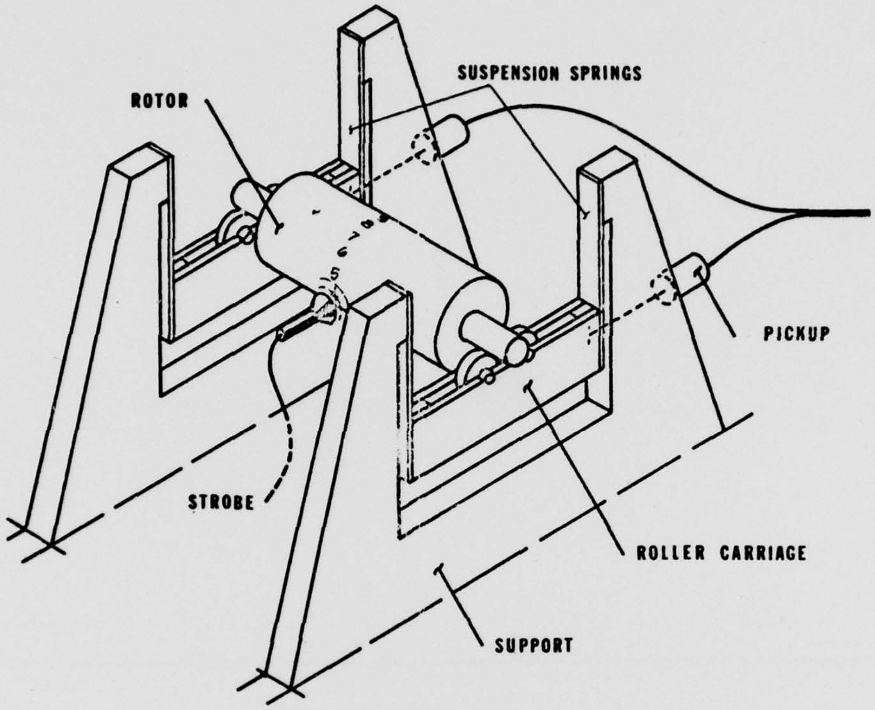


Figure 4. Machine with Electrical Indicating System Using Stroboscopic Lamp for Angle Indication. The suspension led to the name soft-bearing balancing machine

of unbalance at a given speed is always the same, regardless of whether the unbalance occurs in a small or large or light or heavy workpiece. Direct measurement of this force permits permanent calibration of the indication system of the hard-bearing machine in ounces or grams for all workpieces within its capacity. Such calibration is not possible with soft-bearing machines because a specific amount of unbalance causes different amplitudes of vibration in different types of rotors, depending on such factors as mass and configuration of workpiece, moments of interia, mass of the balancing machine suspension, and balancing speed.

A seldom recognized prob[...] bearing machines is the skill required t[...] appropriate

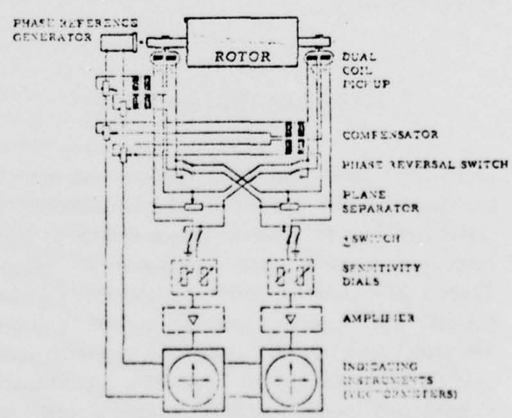


Figure 5. Fully Developed Indicating System of Soft-Bearing Balancing Machine

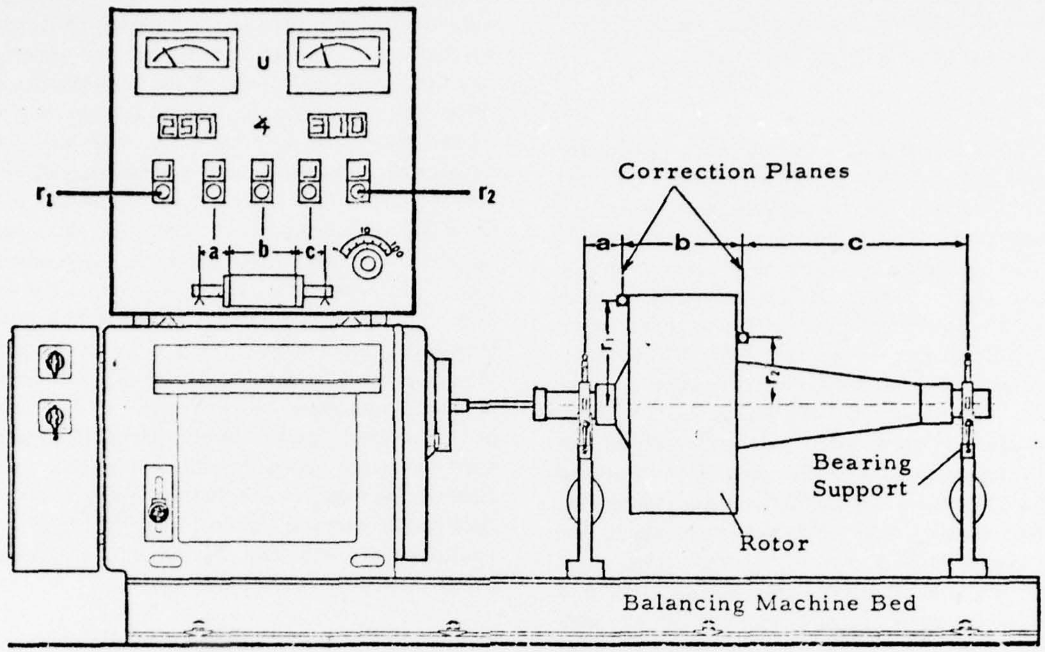


Figure 6. Typical Hard-Bearing Balancing Machine with Permanently Calibrated Instrumentation. Rotor Dimensions a, b, c and r_1, r_2 are directly dialed into the analog computer

test weight size and suitable calibration. Estimations of the maximum expected initial unbalance require experience, as do comparisons to the specified tolerance and determination of a calibration setup that will provide a readable indication of both. Correct judgment of this relationship determines to a great extent the eventual capability of a soft-bearing machine to indicate a large initial unbalance and a small final tolerance.

Size, weight, or shape of a workpiece change frequently in most types of balancing applications, particularly in short production runs, maintenance and repair work, and shop balancing. In such instances, the hard-bearing, permanently calibrated machine is most valuable because it provides the operator with an immediate, first-run readout of unbalance. Because most hard-bearing balancing machines have a dual channel indicating system, readings for both correction planes are shown simultaneously.

Occasionally, a workpiece has to be balanced at more than one speed. This is not particularly difficult if a hard-bearing machine is used because built-in electronic circuitry maintains permanent calibration throughout the speed range. On the other hand, a soft-bearing machine must be recalibrated for each balancing speed; weights are attached to the rotor for each calibration. Problems often occur. Typically, for example, the weights used are lumps of either clay or wax. Even though they are carefully weighed, errors can be introduced when they are attached to the workpiece because it is difficult to position the center of gravity of such a lump at any exact radius or angular position. Such positioning errors result in calibration errors. In addition, the peripheral speed of the rotor is sometimes such that the clay flies off; specially made bolt-on weights or something similar must then be used. In addition weights temporarily attached to a workpiece pose some danger to operators.

On some soft-bearing machines small shakers are mounted to the supports to eliminate the calibration weight problem. These machines are calibrated with the shaker force when the rotor is not turning. However, the fact that these machines do not account for the polar moment of inertia of the rotor significantly affects the accuracy of calibration for any but a narrow range of rotors of standard shape.

Even limited calibration requires that the operator adjust a series of dials and switches in a prescribed sequence. In principle, he vibrates the rotor on the machine supports with built-in shakers that produce a force equivalent to a known unbalance in the bearing plane. Shaker frequency must conform precisely with the intended balancing speed. Next, an A-B-C network is set to refer the calibration weight simulation to the correction planes. Another set of dials adjusts for the radius of correction. Only after all these steps have been carried out can the actual amount be calibrated; eight additional dials are necessary to establish a fixed relationship between shaker force and unbalance readout. The same shaker force is used for all rotor sizes, initial unbalances, and tolerance requirements. This is a severe limitation when rotor requirements vary over a wide range. Furthermore, the entire process must be repeated if the balancing speed is changed or a rotor of a different size is to be balanced.

These frequently overlooked difficulties inherent in the calibration procedure of soft-bearing machines point out the basic ease and simplicity of the newer, hard-bearing machines. Sensitivity and accuracy are built into the hard-bearing machine; on a soft-bearing machine, however, they are entirely dependent on how well the operator calibrates the machine for the given part.

Permanent calibration in no way compromises the capability of a hard-bearing machine to measure extremely large unbalances. Quite the contrary! A hard-bearing machine will indicate very large initial unbalances that would be impossible to measure with soft-bearing machines because the large vibration amplitudes would exceed the limits of the pickups.

Another important advantage of hard-bearing machines is that they eliminate wind disturbances when blowers and fans are balanced. The workpiece rotates as if it were assembled, and there is no swinging of the supports as can occur with soft-bearing machines. Thus the unbalance signals are not distorted.

Although extremely sensitive, the hard-bearing suspension system is rugged and cannot be damaged by chips, grit, and dirt. One further and sometimes very important advantage of the hard-bearing machine is its capability to balance at extremely low speeds, something a soft-bearing machine cannot do because its balancing speed must always be considerably higher than the natural frequency of the rotor and vibratory support system so that a stable readout is obtained for the calibration. Low balancing speeds greatly reduce the horsepower requirements of a machine on which rotors with large moments of inertia or considerable drag are to be balanced. Horsepower required to accelerate a given moment of inertia decreases proportionally to the square of the balancing speed. Horsepower required to run a fan decreases approximately proportional to the cube of the speed. A low balancing speed can thus significantly decrease the cost of the drive, of other related components, and thereby of the entire machine -- in addition to saving energy.

The advantages cited above are sufficient reasons for the dominant position in the field of balancing acquired by the hard-bearing system during the past 15 years. Not surprisingly, the system is now at the forefront of a new developmental stage -- computerization. All hard-bearing instrumentation has heretofore included a manually operated analog computer. This can now be replaced by an on-line digital computer which transforms the art of balancing into a routine task. Computerization greatly simplifies the mating of a balancing machine with such correction devices as a drill head or milling machine, thereby allowing low cost automation when many pieces of the same type and size are to be balanced. Such automation was previously practiced almost exclusively in the automotive industry but has now become economical for many other applications involving shorter production runs.

REFERENCES

1. ISO 1925. Balancing Vocabulary.

2. McQueary, D.E., "Understanding Balancing Machines," American Machinist Special Rept. No. 656 (June 11, 1973).

3. Federn, K., Auswuchttechnik, 1, Springer Verlag (1977).

4. Harris, C.M. and Crede, C.E., Eds., Shock and Vibration Handbook, Second Edition, McGraw-Hill (1977).

LITERATURE REVIEW

survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four review articles each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the DIGEST reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

Current work on transonic blade flutter research is summarized by Professor Platzer of the Naval Postgraduate School. Aerodynamic theory and flow models are reviewed.

Professor Norman Jones of Massachusetts Institute of Technology has written a two part article on recent progress on the dynamic plastic behavior of structures. Part I on the behavior of ideal fiber-reinforced beams, higher modal response, transverse shear and rotary inertia effects, fluid-structure interaction, and dynamic plastic buckling is published in this issue of the DIGEST.

TRANSONIC BLADE FLUTTER: A SURVEY OF NEW DEVELOPMENTS

M.F. Platzer*

***Abstract** - This paper is a review of current work in transonic blade flutter research. Aerodynamic theory and flow models are summarized. Analyses of supersonic and transonic flow past oscillating cascades, blade row interactions, and three-dimensional unsteady flow through rotating annular cascades are given. Experimental studies are described.*

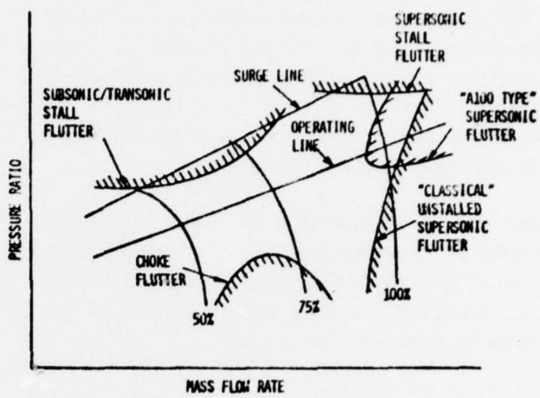
An earlier survey [1] presented a general description of the transonic blade flutter phenomenon and summarized the analytical and experimental investigations devoted to the problem prior to 1975. This paper updates the current status of transonic blade flutter research.

The term transonic flutter is used here to indicate that the flow over the outer span of a blade is either transonic or supersonic. Depending on the flow condition, any of three types of flutter can occur:

- transonic choke flutter, when the blade is operating at near-choke conditions
- supersonic unstalled flutter, when the attached flow over the outer span of the blade is fully supersonic
- supersonic stall flutter, while the outer portion of the blade is operating supersonically but the flow is partly or fully separated

Typical flutter boundaries that have been observed on modern compressors are shown in the figure. The choke flutter boundary is encountered during part-speed operation. The blades operate transonically at negative incidence angles and, due to a choked flow, in-passage shocks with possible flow separations are likely to occur.

The supersonic unstalled flutter boundary imposes an important high-speed operating limit. Recent tests have shown that the blade flutter mode during this type of flutter can be either predominantly torsional or consist of a large vibrational deformation of the blade camber line (chordwise bending mode). Still another type of supersonic torsional flutter,



Types of Fan/Compressor Flutter [66]

designated A-100 flutter, was recently identified; it occurred only above a threshold level pressure ratio. Two additional flutter boundaries may be encountered during operation near surge: supersonic stall flutter and subsononic stall flutter. The latter phenomenon has plagued the engine industry for many years but is outside the scope of this paper. Supersonic stall flutter, however, is still largely unexplored due to the enormously complex nature of separated supersonic flow through transonic rotors.

Subsequent sections of this review are limited to a discussion of transonic choke flutter and supersonic unstalled flutter. The interested reader is referred to recent reviews by Sisto [65], Fleeter [66], and Platzer [68] for discussions of other aeroelastic problems in turbomachines.

*Professor of Aeronautics, Naval Postgraduate School, Monterey, CA 93940

AERODYNAMIC THEORY

It has been pointed out [1] that considerable simplifications are required in order to make the problem of transonic blade flutter mathematically tractable. To this end, viscous flow effects are usually ignored at the outset, and the analysis is based on Euler equations or some suitable approximation of them. The fully linearized approximation has been the most widely used, but attempts have recently been made to include nonlinear flow effects.

Linear analysis assumes that the major effects are described by small perturbations of a uniform flow of velocity U in the x direction. Therefore, the well-known linearized unsteady potential equation for the velocity potential φ can be used.

$$\frac{1}{c^2}\left(\frac{\partial}{\partial t} + U\frac{\partial}{\partial x}\right)^2 \varphi = \nabla^2\varphi \qquad (1)$$

In equation (1) c represents the constant velocity of sound of the uniform flow. Solution methods for this equation have been well developed and documented [2, 3, 71]. Unfortunately, equation (1) is only conditionally valid for describing wave propagation phenomena in flows with mixed subsonic/supersonic flow regions. As has been shown [4, 5] the propagation must occur at sufficiently high frequency for equation (1) to be valid, or more precisely

$$k >> |1 - M_L|$$

M_L is the local Mach number and k the reduced frequency.

In nonlinear analyses nonlinear flow effects can be incorporated by basing the analysis either on the transonic small perturbation equation [5]

$$[1 - M^2 - (\gamma + 1)\frac{M^2}{U}\varphi_x]\varphi_{xx} + \varphi_{yy} - \frac{1}{c^2}\varphi_{tt} - 2\frac{M}{c}\varphi_{xt} = 0 \qquad (2)$$

the full potential flow equation [5], or the Euler equations.

FLOW MODELS

The analysis of three-dimensional unsteady flow through a transonic multi-stage machine is still prohibitively complex. Various simplifying assumptions are made so that the problem is amenable to a mathematical solution.

The most simple and widely used model -- the cascade flow model -- is obtained by unwrapping an annulus of differential radial height from the flow passage of an axial-flow turbomachine. Only one cascade is usually considered because of the complicated interactions between neighboring blade rows. As has been pointed out [1] the case of supersonic cascade flow requires further differentiation depending on the axial through-flow Mach number, which can be either subsonic (causing propagation of the disturbances upstream of the blade leading edges), moderately supersonic (causing interactions only between the reference blade and its adjacent blades), or highly supersonic (causing no interactions between neighboring blades).

Three-dimensional flow models have recently been introduced; examples include the flow past a vibrating blade row of finite blade height situated between end plates and the flow past an annular blade row with a finite number of vibrating blades rotating at a constant angular velocity in an infinitely long cylindrical duct.

ANALYSIS OF SUPERSONIC FLOW PAST OSCILLATING CASCADES

Interest in the analysis of unsteady supersonic cascade flows was stimulated by the need to understand supersonic wind tunnel interference effects [1]. The two problems are closely related because an oscillating airfoil situated between two solid wind tunnel walls is equivalent to an unstaggered cascade whose blades are oscillating in counterphase. Using equation (1), Miles [6] obtained a complete solution by Laplace transform methods.

This work was extended [7-10] to staggered cascades with supersonic leading-edge locus (supersonic axial velocity). Equation (1) was again used with various solution methods.

Analysis of the more practical but more difficult case of supersonic flow past staggered vibrating cascades with a subsonic leading-edge locus (subsonic axial velocity) began only recently. The disturbances are able to propagate upstream of the blade leading edges, thus producing a more complex blade interaction phenomenon. The first treatment seems to have been that of Gorelov [11], who used collocation methods. Solutions for semi-infinite cascades were published almost simultaneously in the U.S. by Verdon [12], Brix and Platzer [13], and Nagashima and Whitehead [14]. The approach assumes a first blade; sufficient additional blades are considered until convergence toward a periodic solution is achieved. Linearized theory restricts the analysis to flat-plate cascades; complete solutions were obtained using different approaches; i.e., finite difference [12], characteristics [13], and singularity methods [14].

The case of an infinite cascade oscillating at low frequency was first considered at about the same time by Kurosaka [15]. He succeeded in enforcing the periodicity condition explicitly and obtained an analytical solution using Laplace transform methods. Other solutions for vibrating flat-plate cascades with subsonic leading-edge locus have been published [16-23]. Adamczyk and Goldstein [23] approached this problem in several new ways: the time marching technique [16], the Wiener-Hopf technique [22, 23], and formulations in terms of two boundary value problems solved successively and represented by infinite series expressions [20, 21]. Comparisons of the various methods indicate substantial agreement, but additional systematic evaluations will be required for a definitive assessment.

The differences between semi-infinite and infinite cascade analyses have recently been studied [24]. An elementary approach was used to develop analytical solutions for slowly oscillating semi-infinite and infinite cascades. The resonance phenomenon in supersonic cascades was first pointed out by Samoylovich [25]. The computation of the aerodynamic forces in the super resonant regime has recently been discussed in some detail [21].

All of the above analyses are based on linearized flow theory and hence are restricted to flat-plate cascades. The effects of blade thickness and loading on supersonic blade flutter are still unresolved. However, work on two approaches has recently begun. One analysis has been based on the nonlinear transonic small disturbance equation and the steady flow field computed by a nonlinear characteristics method upon which the oscillatory flow field was superimposed as a linear perturbation [24]. Preliminary results indicate that flutter is significantly dependent on blade thickness, especially at lower frequencies. Kurosaka [26] used the complete nonlinear potential equation as the governing equation and applied the method of strained coordinates. Results for the cascade are as yet unpublished, but the solution for the oscillating single airfoil has been published [27]. Such methods as the time-marching method are also applicable to the analysis of thickness and loading effects, but apparently no results have been published.

ANALYSIS OF TRANSONIC FLOW PAST OSCILLATING CASCADES

The prediction of transonic cascade flows is hampered by the difficulties involved in computing mixed subsonic/supersonic flows. The problems have recently been reviewed in a workshop on transonic flow problems in turbomachinery [28]. At present, only a few rather simplified oscillatory cascade flow solutions have been published although several recently developed methods are potentially able to provide much better approximations of the actual flow. Hamamoto [29] gave a solution for sonic flow past unstaggered flat-plate cascades oscillating at zero interblade phase angle. He applied Fourier transform methods to the linearized transonic small disturbance equation.

An extension of this analysis to arbitrary interblade phase angles and to cascades with finite blade thickness on the basis of Oswatitsch's parabolic approximation [30], as well as an investigation of other solution techniques, such as Laplace transform and collocation techniques, has recently been studied [31]. This study revealed that cascade interference effects have a strongly destabilizing influence on torsional vibrations for many parameter combinations.

The related problem of sonic wind tunnel interference has also been analyzed [32] using linearized transonic flow theory. In the past few years attempts have also been initiated to account for the presence of transonic shocks. In the first such study [33] transonic flow through a staggered oscillating cascade was examined. Normal shocks were assumed in the blade passages. The flow downstream of the shocks is thus subsonic; the shocks act as reflection planes for the disturbances propagating throughout the subsonic flow region. The shock oscillations were determined, and it was concluded that torsional oscillations are damped by the shock waves. A similar flow model was used with the Wiener-Hopf technique [34]. The results predicted greater torsional stability than the completely supersonic model but also revealed the possibility of supersonic bending flutter.

The limitations of the above approaches can be fully assessed only by comparison with more accurate procedures. Computation of transonic flow past a single oscillating airfoil using the time marching technique was the first exact solution to this problem [35]. As has already been mentioned, this technique has been applied to oscillating flat-plate cascades [16]. Efforts are presently underway to apply the technique to oscillating cascades with arbitrary blade shapes; the results will provide a valuable standard for evaluating more approximate but faster procedures. Among such procedures, the relaxation method is promising although results are apparently available only for single oscillating airfoils [36].

The vibration characteristics of transonic turbine cascades have recently been investigated [37]. Shock motion in transonic channel flows has also been studied [38-41]. Asymptotic expansion procedures were used to study shock formation and propagation responses to small downstream pressure disturbances. Depending upon the initial conditions imposed, either small or large amplitude shock wave motions can occur, even when the shock wave travels upstream from the throat, disappears, and then reappears at the throat. Such behavior is similar to the shock wave motions on an airfoil with an oscillating flap in transonic flow [42]; either sinusoidal shock wave motion, interrupted shock wave motion, or upstream propagated shock wave motion was observed. The aerodynamic response can easily induce blade flutter, but no such computations have yet been performed based on Adamson's model [38-41].

ANALYSIS OF BLADE ROW INTERACTIONS

Few analytical or computational studies have been performed on transonic/supersonic blade row interactions because the flow phenomena are very complex. Unsteady supersonic rotor/stator interference occurs only in machines with subsonic axial through-flow velocities; such interferences were apparently first considered in 1953 [43]. Linearized unsteady flow theory was used to study the wave formations and interactions between stator and rotor, but no complete solution could be obtained. The analysis was restricted to supersonic absolute flow.

In a recent paper [44] subsonic absolute flow out of the stator was considered; wave diffractions and reflections on the stator vanes were studied by observing the shock waves formed at the leading edges of the rotor blades. It was found that unsteady pressures were generated on the vanes and that these pressures can excite bending and torsional vibrations. Schlieren-optical cascade investigations in a shock tube appeared to confirm the theoretical analysis. Other experimental studies of blade row interactions in high-speed machines are described below.

ANALYSIS OF THREE-DIMENSIONAL UNSTEADY FLOW THROUGH ROTATING ANNULAR CASCADES

The adequacy of the two-dimensional cascade flow model can be assessed only by comparisons with well-controlled experiments in rotating test rigs or by the development of fully three-dimensional solutions. Work on such solutions has been undertaken in recent years in both France and Japan. The theoretical model considered by Salaun [45, 46] and Namba [47] consists of a single annular blade row with a finite number of blades rotating at a constant angular velocity in a cylindrical annular duct. The blades are assumed to vibrate harmonically at small amplitude, thus making possible the linearization of the Euler equations and the continuity equations about the helical base flow. Lifting surface methods were used to solve the resulting boundary value problem for the case of subsonic base flow; interesting numerical results were given. According to Namba [47], three-dimensional effects are small if the reduced frequency of vibration is well above the resonance frequency of the predominant acoustic mode, but aerodynamic damping decreases below the level predicted by strip theory in the subresonant regime. The conclusion is that three-dimensional effects cause a reduction in flutter velocity. Equally significant deviations from strip theory were found by Salaun [46], who also obtained as yet unpublished results for supersonic flow [48].

FLUTTER ANALYSIS

The flutter analysis of a blade row is considerably simplified by the application of Lane's theorem [49], which permits consideration of a single equivalent blade, thereby reducing the problem to that of a wing flutter analysis. Blades vibrating only in torsion can therefore be analyzed in a short time by determining the aerodynamic pitch damping as a function of interblade phase angle. Chordwise bending flutter and blades exhibiting plate-type deformations in flutter require more laborious procedures [77]. A detailed description of the blade flutter theory can be found in Samoylovich's text [71].

EXPERIMENTAL STUDIES

A number of experimental programs are currently in progress or have already been completed since 1975 [1]. The supersonic torsional cascade flutter tests conducted at the United Technologies Research Laboratories (UTRL) [1] have been expanded to include chordwise bending flutter tests. The possiblity that supersonic unstalled flutter could involve a large vibrational deformation of the blade camber line (chordwise bending) was discovered on very high-speed fans built of composite materials. Tests of typical high-speed fan blades in the supersonic cascade tunnel at UTRL verified the existence of supersonic unstalled flutter. Linearized aerodynamic theory as stated in equation (1) could predict basic trends although important quantitative differences remained unresolved [53].

Complete understanding of the flutter phenomenon requires knowledge of unsteady blade pressure distributions. The purpose of a comprehensive measuring program now underway at Detroit Diesel Allison is to determine the pressure distributions and their phase relations to blade motion. The tests are performed in the Allison supersonic cascade tunnel using electromagnetically driven blades and Kulite pressure transducers. Projects completed to date include measurements on blades with diamond-back profiles and multiple circular arc profiles [54-57]. Further tests are planned to investigate the characteristics of high-turning turbine cascades.

Unsteady cascade testing is also being carried out in Europe and Japan. At DFVLR-AVA Goettingen, Germany, Bublitz [58] investigated the aeroelastic characteristics of a nine-bladed highly cambered turbine cascade in the Mach range 0.4 to 1.0. During transonic operation large pressure fluctuations and dynamic stresses were observed. Lawaczek and Heinemann [59], also at DFVLR-AVA Goettingen, measured the Karman vortex street shed from a ten-bladed turbine cascade exposed to subsonic, transonic, and supersonic flow. At ONERA, France a cascade tunnel that permits subsonic, transonic, and supersonic unsteady cascade tests has apparently been completed [60]. Transonic cascade flutter tests have also been reported in the Russian literature [61], and recent surveys of current Russian work on aeroelasticity in turbomachines have been published [62-64].

A recently completed experimental and analytical study [67] demonstrated transonic choke flutter for an airfoil free to oscillate in torsion about the mid-chord between parallel walls in transonic flow. This instability was predicted using a one-dimensional flow analysis. The phenomenon is similar to the well-known transonic aileron buzz, which has been investigated by Tijdeman [42].

Tests in annular cascades are simulating the unsteady aerodynamic and aeroelastic phenomena that occur in transonic turbomachines. An annular cascade of 16 blades permits testing at subsonic and supersonic Mach numbers up to 1.4 [69]. Electromagnetic excitation of the blades is used; the aerodynamic moments due to torsional oscillations over a Mach number range from 0.6 to 1.2 are measured. Both a fixed and a rotating supersonic annular cascade are available at ONERA and have been used [70] to study the unsteady flow phenomena and shock motions caused by over-speed operation of a transonic compressor. An annular cascade research program at Detroit Diesel Allison [66] has been designed to obtain subsonic and transonic flutter boundaries in the stall and choke flutter regimes.

Another important test program recently completed at Detroit Diesel Allison [72] concerned demonstrating the feasibility of scaled model flutter tests; the purpose was to acquire full-scale flutter data at a fraction of the cost of full-scale engine or rig tests. The subsonic stall flutter boundaries of the model and rig were in excellent agreement. Unfortunately, for as yet unknown reasons, a similar correlation between the supersonic flutter boundaries of the full-scale fan and the model was not obtained.

The amount of detailed unsteady aerodynamic and flutter information obtained in full-scale engines is, of course, limited due to the expense and complexity involved in such tests although a number of flutter incidents have occurred. Considerable progress has been made in recent years in acquiring oscillating pressure and velocity information in rotating rigs and full-scale engines using high-response pressure transducers and non-intrusive measuring techniques (e.g., laser-doppler velocimetry, holography). A summary of the measurements in transonic turbomachines has recently been assembled [73] in an overview of the current status of these efforts. It suffices, therefore, to refer only to a few particularly noteworthy efforts, such as the blade row interaction studies of Arnoldi [74] and Gallus et al [75] and the laser measurements in a transonic compressor obtained by Weyer and Schodl [76].

SUMMARY AND OUTLOOK

A number of advancements have occurred since the last review of transonic blade flutter research in 1975 [1]. Progress has been made in predicting supersonic flow past oscillating flat-plate cascades with subsonic leading-edge locus, but additional systematic comparisons of the various approaches are needed in order to assess their reliability and computational efficiency.

The limitations of the flat-plate cascade model are now better understood. Analyses of blade thickness, camber, and three-dimensional flow effects are underway, but no definitive results have yet been published.

Transonic flow past oscillating cascades has received considerable attention, and simplified shocked flow models have been proposed and analyzed. An assessment of the validity of these models awaits further theoretical and experimental studies.

Steady progress has also been made in conducting well-controlled and instrumented measurements in cascade tunnels, scaled model test rigs, and full-scale machines. These experiments, together with the theoretical approaches, have begun to provide a useful body of information that will serve as a guide to the flutter-free design of high-performance transonic turbomachines. However, much further systematic theoretical and experimental work is clearly required before the complex aeroelastic phenomena occurring in these machines is sufficiently understood to provide reliable design information.

ACKNOWLEDGMENT

Preparation of this review was supported by the Naval Air Systems Command, Code AIR-310.

REFERENCES

1. Platzer, M.F., "Transonic Blade Flutter - A Survey," Shock Vib. Dig., 7, pp 97-106 (July 1975).

2. Bisplinghoff, R.L., Ashley, H., and Halfman, R.L., Aeroelasticity, Addision-Wesley (1955).

3. Jones, W.P. (Ed.), "Manual on Aeroelasticity," Part II, Aerodynamic Aspects, Advisory Group Aeronaut. Res. Devel. (1962).

4. Lin, C.C., Reissner, E., and Tsien, H., "On Two-Dimensional Nonsteady Motion of a Slender Body in a Compressible Fluid," J. Math. Phys., 27 (3), pp 220-231 (1948).

5. Landahl, M., Unsteady Transonic Flow, Pergamon Press (1961).

6. Miles, J.W., "The Compressible Flow Past an Oscillating Airfoil in a Wind Tunnel," J. Aeronaut. Sci., 23 (7), pp 671-678 (1956).

7. Lane, F., "Supersonic Flow Past an Oscillating Cascade with Supersonic Leading Edge Locus," J. Aeronaut. Sci., 24 (1), pp 65-66 (1957).

8. Hamamoto, I., "Minute Harmonic Oscillation of Flat Plate Cascade in Supersonic Flow," Second Japanese Natl. Congr. Appl. Math. Mech. (May 1957).

9. Gorelov, D.N., "Oscillations of a Plate Cascade in a Transonic Gas Flow," Mekhanika Zhidkosti i Gaza, 1 (1), pp 69-74 (1966).

10. Platzer, M.F. and Chalkley, H.G., "Theoretical Investigation of Supersonic Cascade Flutter and Related Interference Problems," AIAA/ASME/SAE 13th Struc., Struc. Dynam. Matl. Conf., San Antonio, TX, AIAA Paper No. 72-377 (Apr 10-12, 1972).

11. Gorelov, D.N., "Lattice of Plates in an Unsteady Supersonic Flow," Mekhanika Zhidkosti i Gaza, 1 (4), pp 50-58 (1966).

12. Verdon, J.M., "The Unsteady Aerodynamics of a Finite Supersonic Cascade with Subsonic Axial Flow," J. Appl. Mech., Trans. ASME, pp 667-671 (Sept 1973).

13. Brix, C.W., Jr. and Platzer, M.F., "Theoretical Investigation of Supersonic Flow Past Oscillating Cascades with Subsonic Leading Edge Locus," AIAA 12th Aerosp. Sci. Mtg., Washington, D.C. AIAA Paper No. 72-14 (Jan 30-Feb 1, 1974).

14. Nagashima, T. and Whitehead, D.S., "Aerodynamic Forces and Moments for Vibrating Supersonic Cascade Blades," CUED/A-Turbo/TR-59, Cambridge Univ. (1974).

15. Kurosaka, M., "On the Unsteady Supersonic Cascade with a Subsonic Leading Edge -- An Exact First Order Theory," J. Engr. Power, Trans. ASME, pp 13-31 (Jan 1974).

16. Ni, R.H. and Sisto, F., "Numerical Computation of Nonstationary Aerodynamics of Flat Plate Cascades in Compressible Flow," J. Engr. Power, Trans. ASME, 98 (2), pp 165-170 (Apr 1976).

17. Yates, J.E., "Analysis of Supersonic Unsteady Cascades with the Method of Characteristics," AFFDL-TR-75-159 (Dec 1975).

18. Kurosaka, M., "Supersonic Cascade Study," sponsored by Air Force Office Sci. Res. (1977).

19. Caruthers, J.E., "Theoretical Analysis of Unsteady Supersonic Flow Around Harmonically Oscillating Turbofan Cascades," Ph.D. Thesis, Georgia Tech. (Sept 1976).

20. Verdon, J.M. and McCune, J.E., "Unsteady Supersonic Cascade in Subsonic Axial Flow," AIAA J., 13 (2), pp 193-201 (Feb 1975).

21. Verdon, J.M., "Further Developments in the Aerodynamic Analysis of Unsteady Supersonic Cascades," ASME Papers No. 77-GT-44 and 45.

22. Goldstein, M.E., "Cascade with Subsonic Leading Edge Locus," AIAA J., 13 (8), pp 1117-1119 (Aug 1975).

23. Adamczyk, J.J. and Goldstein, M.E., "Unsteady Flow in a Supersonic Cascade with Subsonic Leading-Edge Locus" (submitted to AIAA J.).

24. Strada, J.A., Chadwick, W.R., and Platzer, M.F., "Aeroelastic Stability Analysis of Supersonic Cascades," Intl. Gas Turbine Conf., London, April 9-13, 1978, ASME Paper No. 78-GT-151.

25. Samoylovich, G.S., "Resonance Phenomena in Sub- and Supersonic Flow through an Aerodynamic Cascade," Mekhanika Zhidkosti i Gaza, 2 (3), pp 143-144 (1967).

26. Kurosaka, M. and Edelfelt, I.H., "Some Recent Developments in Unsteady Aerodynamics of a Supersonic Cascade," Revue Francaise de Mecanique, Numero Special, pp 57-64 (1976).

27. Kurosaka, M., "Cumulative Nonlinear Distortion of an Acoustic Wave Propagating through Non-Uniform Flow," J. Fluid Mech., Trans. ASME, 83, Pt. 4, pp 751-773 (1977).

28. Adamson, T.C. and Platzer, M.F. (Eds), "Transonic Flow Problems in Turbomachinery," Hemisphere Publishing (1977).

29. Hamamoto, I., "Minute Harmonic Oscillations of a Flat Plate Cascade in Transonic Flow," Proc. 10th Japanese Natl. Congr. Appl. Mech.,

pp 227-231 (1960).

30. Oswatitsch, K. and Keune, F., "The Flow around Bodies of Revolution at Mach Number One," Proc. Conf. High Speed Aeronaut., Polytech. Inst. Brooklyn, New York (Jan 1955).

31. Schlein, P.B., "A Study of Unsteady Transonic Interference Effects," Ph.D. Thesis, Naval Postgraduate School, Monterey, CA (Mar 1975).

32. Savkar, S.D., "A Note on Transonic Flow Past a Thin Airfoil Oscillating in a Wind Tunnel," J. Sound Vib., 46 (2), pp 195-207 (1976).

33. Gorelov, D.N. and Meshman, V.A., "On Unsteady Flow with Shocks in Supersonic Compressor Cascades," P.M.T.F. (Russian Journal for Applied Mechanics and Technical Physics) No. 5, p 41 (1973).

34. Goldstein, M.E., Braun, W., and Adamczyk, J.J., "Unsteady Flow in a Supersonic Cascade with Strong In-Passage Shocks," J. Fluid Mech., Trans. ASME, 83, Pt. 3, pp 569-604 (1977).

35. Magnus, R.J. and Yoshihara, H., "Calculations of Transonic Flow over an Oscillating Airfoil," AIAA 13th Aerosp. Sci. Mtg., Pasadena, CA, AIAA Paper No. 75-98 (Jan 20-22, 1975).

36. Seebass, A.E., Yu, N.J., and Fung, K.Y., "Unsteady Transonic Flow Computations," Proc. AGARD Symposium on Unsteady Aerodynamics, Ottawa, Canada (Sept 26-28, 1977).

37. Pigott, R., "Forced and Self-Excited Vibration of Transonic Turbine Cascades," Ph.D. Thesis, Univ. Pennsylvania, Philadelphia (1975).

38. Adamson, T.C., Jr. and Liou, M.S., "Unsteady Motion of Shock Waves in Two-Dimensional Transonic Channel Flows," Univ. Michigan Rept. UM014534-F (June 1977).

39. Richey, G.K. and Adamson, T.C., Jr., "Analysis of Unsteady Transonic Channel Flow with Shock Waves," AIAA J., 14, pp 1054-1061 (1976).

40. Messiter, A.F. and Adamson, T.C., Jr., "Asymptotic Solutions for Nonsteady Transonic Channel Flows," Symposium Transsonicum II (Oswatitsch, K. and Rues, D., Eds.) Springer Verlag, pp 41-48 (1976).

41. Adamson, T.C., Jr. and Messiter, A.F., "Normal Shock Wave-Turbulent Boundary Layer Interactions in Transonic Flow Near Separation," Transonic Flow Problems in Turbomachinery (Adamson, T.C., Jr. and Platzer, M.F., Eds.) Hemisphere Publishing (1977).

42. Tijdeman, H., "Investigations of the Transonic Flow around Oscillating Airfoils," Ph.D. Thesis, Tech. Univ. Delft, The Netherlands (Dec 1977).

43. Ryhming, I., "Uber die instationare Uberschallstromung durch Schaufelgitter mit Ruckwirkung," Z. Angew. Math. Mech., 37 (11/12), pp 416-431 (Dec 1957).

44. Favrat, D. and Suter, P., "Interaction of the Rotor Blade Shock Waves in Supersonic Compressors with Upstream Stator Vanes," ASME *Paper No. 77-GT-93* (1977).

45. Salaun, R., "Unsteady Aerodynamic Pressures in an Annular Cascade in Subsonic Flow," Ph.D. Thesis, Univ. Paris (May 1974).

46. Salaun, R., "Flutter Instability in an Annular Cascade," Revue Francaise de Mecanique, Numero Special, pp 35-38 (1976).

47. Namba, M., "Lifting Surface Theory for Unsteady Flows in a Rotating Annular Cascade," Revue Francaise de Mecanique, Numero Special, pp 39-46 (1976).

48. Salaun, R., Private Communication (1976).

49. Lane, F., "System Mode Shapes in the Flutter of Compressor Blade Rows," J. Aeronaut. Sci., pp 54-66 (Jan 1956).

50. Synder, L.E., "Supersonic Torsional Flutter in Cascades," Pratt & Whitney TR-PWA-TM-4701 (Apr 1973).

51. Snyder, L.E. and Commerford, G.L., "Supersonic Unstalled Flutter in Fan Rotors, Analytical

and Experimental Results," J. Engr. Power, Trans. ASME, pp 379-386 (Oct 1974).

52. Mikolajczak, A.A., Arnoldi, R.A, Snyder, L.E., and Stargardter, H., "Advances in Fan and Compressor Blade Flutter Analysis and Predictions," AIAA J. Aircraft, 12 (4), pp 325-332 (Apr 1975).

53. Arnoldi, R.A., Carta, F.O., St. Hilaire, A.O., and Dalton, W.N., "Supersonic Chordwise Bending Flutter in Cascades," Pratt & Whitney Rept. No. PWA-5271 (May 1975).

54. Fleeter, S., McClure, R.B, Sinnet, G.T., and Holtman, R.L., "Supersonic Inlet Torsional Cascade Flutter," J. Aircraft, 12 (8) (Aug 1975).

55. Fleeter, S., Novick, A.S., and Riffel, R.E., "An Experimental Determination of the Unsteady Aerodynamics in a Controlled Oscillating Cascade," J. Engr. Power, Trans. ASME, 99 (1) (Jan 1977).

56. Fleeter, S. and Riffel, R.E., "An Experimental Investigation of the Unsteady Aerodynamics in an Oscillating MCA Airfoil Cascade Including Loading Effects," Office Naval Res. Tech. Rept., Detroit Diesel Allison EDR 9028 (Dec 1976).

57. "Experimental Determination of Unsteady Blade Element Aerodynamics in Cascades," Detroit Diesel Allison, NASA Contract NAS3-20055.

58. Bublitz, P., "Experimental Aeroelastic Investigation on a Cascade in Compressible Flow," Revue Francaise de Mecanique, Numero Special, pp 143-150 (1976).

59. Lawaczek, O. and Heinemann, H.J., "Von Karman Vortex Streets in the Wakes of Subsonic and Transonic Cascades," Revue Francaise de Mecanique, Numero Special, Complement, pp 9-16 (Oct 1976).

60. Loiseau, H. and Maquennehan, B., "Aeroelastic Instabilities in Compressors and Wind Tunnel Tests of Straight Cascades," Revue Francaise de Mecanique, Numero Special, pp 157-168 (1976).

61. Tikhonov, N.D., "Influence of the Geometrical Parameters of the Profile and Cascade on the Critical Flutter Velocity of a Pack of Compressor Blades," Problemy Prochnosti, (8), pp 57-62 (Aug 1974).

62. Samoylovich, G.S., "Excitation of the Fluctuations of the Blades of Turbomachines," Mashinostroyeniye, Moscow (1975).

63. Pisarenko, G.S. and Ol'shtein, L.E., "Problems of Aeroelasticity of Blades of Turbomachines," Problemy Prochnosti, pp 3-8 (Aug 1974).

64. Ol'shtein, L.E., "New Aspects of the Aeroelasticity of Turbomachines," Problemy Prochnosti, pp 3-6 (Mar 1976).

65. Sisto, F., "A Review of the Fluid Mechanics of Aeroelasticity in Turbomachines," J. Fluids Engr., Trans. ASME, pp 40-44 (Mar 1977).

66. Fleeter, S., "Aeroelasticity Research for Turbomachine Applications," AIAA Paper No. 77-437.

67. Tanida, Y. and Saito, Y., "A Study on Choking Flutter," Revue Francaise de Mecanique, Numero Special, pp 151-156 (1976).

68. Platzer, M.F., "Unsteady Flows in Turbomachines -- A Review of Current Developments," Proc. AGARD Symp. Unsteady Aerodynamics, Ottawa, Canada (Sept 1977).

69. Whitehead, D.S., et al., "An Experiment to Measure Moment Coefficients for Aerofoils Oscillating in Cascade," Revue Francaise de Mecanique, Numero Special, pp 123-139 (1976).

70. Paulon, J., "Flow Instabilities in Supersonic Compressors at Low Compression Regime," Revue Francaise de Mecanique, Numero Special, pp 177-186 (1976).

71. Samoylovich, G.S., "Unsteady Flow around an Aeroelastic Vibration in Turbomachine Cascades," Wright-Patterson AFB, OH, Foreign Tech. Div. FTD-HC-23-242-70 (Feb 1971).

72. Jay, R.L., "Subscale Flutter Testing of TF-41-A-100 LP1 Blades," AFAPL-TR-75-82 (Dec 1975).

73. McNally, W.D., "Review of Experimental Work on Transonic Flow in Turbomachinery," Proc. Project SQUID Workshop on Transonic Flow in Turbomachinery, pp 457-484, Hemisphere Publishers (Feb 11-12, 1976).

74. Arnoldi, R.A., "Holographic Visualization of Compressor Blade Wake Interaction," Pratt & Whitney, Final Tech. Rept. No. PWA-TM-4925 (Mar 1974).

75. Gallus, H.E., Bohn, D., and Broichhausen, K.D., "Measurements of Quasi-Steady and Unsteady Flow Effects in a Supersonic Compressor Stage," ASME Paper No. 77-GT-13 (Mar 1977).

76. Dunker, R.J. and Weyer, H.B., "Experimental Study of the Flow Field within a Transonic Axial Compressor Rotor by Laser Velocimetry and Comparison with Trough-Flow Calculations," ASME Paper No. 77-GT-28, Intl. Gas Turbine Conf., Philadelphia (Mar 27-31, 1977).

77. Sisto, F., "Prediction of Supersonic Compressor *Flutter Parameters," Dynalysis Rept. No.* 56 (Apr 1977).

RECENT PROGRESS IN THE DYNAMIC PLASTIC BEHAVIOR OF STRUCTURES PART I

N. Jones*

Abstract - This two-part article reviews the literature on the dynamic plastic response of structures published since 1975. The review focuses on the behavior of such simple structural components as beams, plates, and shells subjected to dynamic loads that cause extensive plastic flow of material.

Part I deals with recent work on the behavior of ideal fiber-reinforced beams, higher modal response of beams, the influence of transverse shear and rotatory inertia, approximate methods of analysis, rapidly heated structures, fluid-structure interaction, and dynamic plastic buckling. Part II contains a discussion of a few numerical studies on the dynamic plastic response of structures and some miscellaneous comments and concluding remarks.

This two-part article surveys recent literature published on the inelastic response of such structural members as beams, plates, and shells subjected to dynamic loads or sudden applied displacements that cause permanent displacements or structural damage. The results of studies on the inelastic response of structural members are applicable in various fields -- for example, the development of rational design procedures to avoid the destructive action of earthquakes on buildings; the improvement of occupant safety during collisions of aircraft, automobiles, buses, and trains; the collision protection of ships and marine vehicles containing hazardous cargoes; estimations of slamming and bow wave damage to ships and other marine vehicles; the design of nuclear reactor tubes to withstand violent transient pressure pulses, of buildings to withstand internal gaseous explosions, and of other energy absorbing systems. Background material [1] concentrated on the nonlinear effects of finite displacements (or geometric changes) and the strain rate sensitivity of materials. In addition, Krajcinovic [2] surveyed the exact theoretical solutions available on the dynamic inelastic behavior of various rigid perfectly plastic structures that undergo infinitesimal displacements. Baker [3] published a survey on approximate techniques for estimating the plastic deformation of structures acted on by impulsive loads, and Rawlings [4] reviewed a wide range of metal structures subjected to dynamic overloads and discussed many applications, particularly concerning automobile safety.

*Professor, Department of Ocean Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

IDEAL FIBER-REINFORCED BEAMS

A beam with straight fibers embedded in a matrix and aligned along the axis is considered transversely isotropic when the plane transverse to the fibers is a plane of isotropy. This beam is strongly anisotropic if the value of Young's modulus associated with axial extension of the fibers is much larger than the values of Young's modulus in the transverse plane and the shear moduli of the matrix. In this circumstance the fibers can be idealized as inextensible with little sacrifice in accuracy. The composite of fibers and matrix is known as an ideal fiber-reinforced beam when, in addition to the properties already mentioned, the material is assumed to be incompressible. This material idealization is a continuum one in which no distinction is made between the behavior of the fibers and the response of the matrix. The static elastic behavior of various ideal fiber-reinforced beams has been discussed [5], and many simple theoretical solutions have been found.

Spencer [6] recently developed a theoretical procedure for studying the dynamic plastic structural behavior of ideal fiber-reinforced (strongly anisotropic) beams. He made the assumptions -- infinitesimal displacements, neglect of material elasticity, and transverse wave propagation -- customarily used to obtain the response of rigid-plastic beams made from an isotropic material; under certain circumstances use of these assumptions leads to results that are in reasonable agreement with tests on experimental models [1]. Spencer [6] examined the response of a beam of finite length initially traveling with a velocity V_0 that suddenly struck a rigid stop. The solution to this problem can be transformed so as to give the behavior of a beam subjected, at the midpoint, to a constant velocity V_0 that is maintained for an infinite duration. In turn this problem is equivalent to the case of a beam of finite length that is struck by an infinite mass M traveling with a velocity V_0.

Theoretical solutions have been developed [7] for the dynamic plastic structural response of various ideal fiber-reinforced (strongly anisotropic) beams with boundary conditions and external dynamic loadings which are easily and reliably reproducible in a laboratory. The theoretical behavior of these beams has also been compared to the corresponding dynamic response of beams made from a rigid perfectly plastic isotropic material. In general it appears that the permanent transverse deflections and durations of response of ideal fiber-reinforced beams loaded dynamically are less than the corresponding values for similar rigid perfectly plastic isotropic beams. These theoretical solutions [6, 7] were developed for a rigid linear strain-hardening ideal fiber-reinforced material.

Spencer re-examined the beam problem he had previously studied [6] and presented a theoretical procedure that could be used for a wider class of strain-hardening materials [8]. The theoretical predictions for an ideal fiber-reinforced rigid plastic beam supported across a span of finite length and loaded impulsively indicated that material strain hardening exercises an important influence on the magnitude of the permanent displacements and the shape of the final deformed profile [9]. Shaw and Spencer [10] examined the behavior of various beams struck by masses; in some cases simple theoretical results were possible only for a linear strain-hardening ideal fiber-reinforced material. No theoretical investigations have apparently been published on the dynamic plastic behavior of ideal fiber-reinforced plates and shells.

It is evident from theoretical studies [7, 9] that the duration of the response and the permanent transverse displacements of ideal fiber-reinforced beams are significantly less than the corresponding quantities in "equivalent" rigid perfectly plastic isotropic beams. Thus it appears that the weight of energy-absorbing systems made from materials characterized as ideal fiber-reinforced rigid-plastic might be considerably lower than that from other materials. However, experimental investigations will be necessary to establish whether or not the ideal fiber-reinforced material model is valid for strongly anisotropic beams loaded dynamically. The cases already examined [7, 9] would be attractive for experimental work because similar rigid-plastic isotropic beams have been investigated.

HIGHER MODAL RESPONSE OF BEAMS

Early interest in the modal response of plastic structures was associated with the development of approximate solution methods; however, with the exception of a two-mass discrete model [11, 12], only primary or fundamental response modes have been examined. It is evident that an infinite number of plastic modes is possible in a continuous structure, as is true with elastic structures. Knowledge of these mode shapes and the accelerations associated with them could contribute to understanding the basic properties of rigid-plastic structures that deform in the plastic range as a result of dynamic loading. Moreover, information concerning the excitation of higher modal plastic deformations might well be applicable to the development of efficient energy-absorbing devices.

Exact theoretical solutions for the first, second, and third modal responses of fully-clamped beams subjected to impulsive velocities having first, second, or third modal shapes have been presented [13]. These theoretical predictions were compared to some permanently deformed profiles measured after a series of higher modal experimental tests on aluminum 6061 T6 511 beams. It was concluded that geometric changes, or finite deflections, had a significant influence on the dynamic response, in accord with previous studies on uniformly loaded beams [1]. A simple theoretical procedure [14] was used to examine a first modal response of a beam. The results confirmed that geometric changes were largely responsible for the discrepancy between experimental results and theoretical predictions developed using an infinitesimal theory.

Infinitesimal and finite-deflection analyses [13] were further generalized [15] to predict any symmetrical or antisymmetrical modal response of impulsively loaded, fully-clamped, rigid, perfectly plastic beams. The numerical elastic-plastic behavior of fully-clamped beams subjected to impulsive modal velocity fields was also examined [15]; the spatial finite-element JET 3C computer program was used [16, 17]. It was evident that results using the simple theoretical rigid-plastic procedure [14], which includes the influence of gemoetric changes, are in fairly good agreement with the numerical elastic-plastic finite-element results. This further confirms the accuracy and reliability of the generalized theoretical method, which has also been compared to some experimental results on beams and rectangular plates [1, 18].

The magnitudes of the dimensionless transverse shear forces (Q/Q_O) -- where $Q_O = \sigma_O H/\sqrt{3}$, σ_O is uniaxial yield stress, and H is beam thickness -- have been estimated from the bending moment distributions predicted by the JET 3C numerical elastic-plastic program for the first three modes [15]. The ratio Q/Q_O increases with an increase in mode number, despite the fact that the dimensionless permanent transverse displacements are smaller for the higher modes. The largest numerical value of Q/Q_O, 0.35, is associated with a third modal response. The excitation of higher modes in structures can generate even larger transverse shear forces. Thus, the transverse shear force can become large for high modes, regardless of the values of the transverse displacements. These observations would appear to justify investigations to establish the importance of transverse shear forces on plastic yielding and to assess the influence of shear deformations on the higher modal response of beams and other structures.

Although pure modal responses are not likely to be excited in most practical problems unless deliberately activated (as in a specially designed energy absorbing system), it is nevertheless apparent that the behavior of complex structures loaded dynamically can involve complicated deformation fields having some of the features of higher modal responses.

INFLUENCE OF TRANSVERSE SHEAR AND ROTATORY INERTIA

Transverse shear forces can influence the response of dynamically loaded rigid-plastic beams more than statically loaded ones [1, 19]. Indeed, it has been demonstrated experimentally [20] and shown theoretically [18] that shear failures can develop at the supports of uniform isotropic beams loaded impulsively. Numerical results [15] also indicate that transverse shear forces can be significant in beams that undergo higher modal dynamic responses. Transverse shear forces also dominate the dynamic response of strongly anisotropic beams [6-10]. The studies cited above involve beams loaded dynamically into the plastic range, but transverse shear effects would also play an important role in the dynamic plastic response of plates and shells.

Considerable uncertainty apparently exists concerning many aspects of the precise role of transverse shear forces, even for the yielding of rigid perfectly plastic beams loaded statically. It has been demonstrated that interaction curves relating bending moment M and transverse shear force Q are not proper yield curves; further support for this viewpoint includes interaction curves for I-beams that are not convex [21].

The role of transverse shear forces on the plastic yielding of beams has recently been examined [22]: some justification was given for using convex yield curves for I-beams within the setting of engineering or classical beam theory. A suitable compromise for I-beams between the simple local (stress resultant) and more rigorous nonlocal (plane stress, plane strain) theories might be achieved by using a local theory [23] with a maximum transverse shear force based only on the web area. It is evident [22] that revised theoretical results [23] now provide an inscribing lower bound curve in the $M/M_O - Q/Q_O$ plane which, because of its simplicity, might be acceptable for many theoretical studies on beams. Furthermore, theoretical predictions [21, 24] have been reasonably approximated by a square yield curve that has also been used to solve various problems in dynamic plasticity [19]. In fact, Hodge's revised results [23] and a square yield curve provide two simple methods for essentially bounding the actual yield curve for an I-beam, as shown in [22].

A number of local and nonlocal theories give similar curves in the $M/M_O - Q/Q_O$ plane for beams with rectangular cross sections [22]; thus whatever theory is most convenient can be used.

Symonds [19] examined the influence of transverse shear forces on the dynamic plastic response of an infinitely long beam struck by a mass traveling with an initial velocity V_o. He simplified the theoretical work with a square curve relating the values of bending moment M and transverse shear force Q required for plastic yielding. More recently, Nonaka [25] used a similar theoretical procedure for a beam simply supported across a span of finite length. The beam was subjected to a blast-type loading -- one that had a peak value at t = 0 and decreased monotonically with time t -- distributed uniformly across the entire span. He presented detailed theoretical results for impulsive loading, rectangular pulse loading, and exponentially decaying loading. In general Nonaka's observations lend further support to those of Symonds, in that transverse shear effects can be important for beams with non-compact cross sections, regardless of the type of dynamic loading, and that such shear effects are important for compact beams subjected to dynamic pressures *much larger than the corresponding static plastic* collapse pressure (e.g., impulsive loading).

No restrictions were placed on the amount of shear sliding at the stationary plastic hinges which developed in the theoretical analyses [19, 25]. However, complete severance occurs when the amount of shear sliding equals the beam thickness [18]. It is thus necessary to assure that this mode of failure does not control the response of a particular beam rather than the theoretical results [19, 25].

The influence of rotatory inertia seems to have been neglected in all analytical investigations on the dynamic plastic response of structures. This situation has prevailed despite many studies of the role of rotatory inertia in various dynamic elastic problems. An exact theoretical procedure that retained the influence of rotatory inertia and transverse shear forces on the dynamic plastic behavior of beams has been developed [26]. The behavior of a long beam struck by a mass and the impulsively loaded simply-supported beam problem of Nonaka [25] were examined using a square yield criterion.

The theoretical predictions for certain parameters [26] indicated that rotatory inertia barely influences the dynamic plastic response of a long wide-flanged I-beam struck by a mass. A greater effect was observed for a simply-supported wide-flanged I-beam loaded impulsively. As expected, rotatory inertia had the most influence on beams with rectangular cross sections. The largest reduction observed in the maximum dimensionless transverse displacements was approximately 11 percent [26]. It appeared that the effect of rotatory inertia on the dynamic plastic response of beams in sensitive to the kind of boundary conditions and the type of loading.

The influence of transverse shear forces and rotatory inertia on the dynamic plastic response of beams with nonlinear yield curves has been examined by a numerical procedure [27].

APPROXIMATE METHODS OF ANALYSIS

A previous review on the dynamic plastic response of structures [1] emphasized the influence of finite deflections, or geometric changes, and material strain rate sensitivity.

Symonds [28] observed that the nonhomogeneous nature of the strain rate sensitive constitutive equations complicates theoretical modal solutions and bounding methods. He replaced the nonhomogeneous relations with simpler homogeneous viscous expressions and found that replacing a rigid viscoplastic constitutive equation with a homogeneous viscous representation did simplify the theoretical analyses. The initial stresses and initial slopes of the dimensionless stress-strain rate provided the best fit to the nonhomogeneous exact and homogeneous viscous curves. The homogeneous matched viscous constitutive relations constructed in this way were then used in theoretical work [29-32]. An upper bound theorem was developed from the theorem of minimum potential energy and used to estimate the permanent displacements of strain rate sensitive structures loaded impulsively [29, 30]. Extremal path concepts [33] were utilized to obtain well-defined functions of specific strain energy and specific complementary strain energy when the influence of finite-deflections was retained in the basic equations. The extremal paths for homogeneous viscous relations between stress and strain rate were simple [29].

The response of the dynamic problem was compared to the behavior of the same structure subjected to a static loading, which produces stresses and strains that follow an extremal path. When static loading was taken as a concentrated force, an upper bound on the displacement at the same location for the dynamic problem could be found [29] if the total strain energy of the static problem was equal to the initial kinetic energy for the dynamic problem [29]. Unfortunately, the upper bound theorem requires knowledge of the duration of the response, for which no rigorous bounds exist when finite deflections and material strain rate effects are retained in the basic equations. However, the theoretical predictions were not very sensitive to the actual value of the response duration, so that either Martin's time bound [34] or an approximation [29] could be used.

The upper bound theorem was used to examine simple structural models having one or two degrees of freedom [29, 30]. The upper displacement bounds for the one-degree-of-freedom model were almost equal to the exact maximum displacements. The upper bound theorem was also used to study an impulsively-loaded fully-constrained beam with a sandwich cross section. The theoretical predictions for the maximum permanent transverse displacements were compared [29] to corresponding experimental results [35]. The upper bound predictions, although accurate at the lower impulse levels are significantly above experimental results for large impulses that are responsible for maximum permanent transverse displacements greater than about five beam thicknesses. The theorem was not used for a rigid perfectly plastic material; thus, it is not known whether approximations associated with geometric changes, strain rate sensitive relations, or both require refinement to improve the estimates at larger impulse levels.

Symonds and Chon [31, 32] also examined modal approximation techniques for strain rate sensitive structures when the influence of finite deflections, or geometric changes, were retained in the basic equations. The modal responses considered above (see Higher Modal Response of Beams) were associated with structural problems in which external loading was responsible for an exact structural response having a velocity profile with a time-independent shape; i.e., modal response. However, the mode approximations [31, 32] followed other work [36] in that the behavior of any dynamic problem can be approximated with a modal response.

If the same modal form remains valid throughout an entire structural response, it is said to be a "permanent"[1] mode form solution. On the other hand, a sequence of mode form solutions might be required in certain classes of problems; e.g., when geometric changes are retained in the basic equations. The initial velocity field in a theoretical solution using a mode approximation is not the same as the initial velocity distribution of the corresponding impulsive loading problem, except in exceptional circumstances. Martin and Symonds [36] developed a criterion for judiciously selecting the magnitude of a modal velocity field in order to minimize the error due to the different initial conditions. More recently, Chon and Martin [11] examined the mode approximation method for a simple two-degrees-of-freedom viscoplastic beam. This theoretical work was developed for structures that undergo infinitesimal displacements; the influence of finite displacements has not yet been incorporated in the work.

A two-degrees-of-freedom beam problem, consisting of two masses connected by massless links has been studied [30]; a stationary mode solution was obtained when the end supports were free to move inward. If the supports were restrained axially, however, it was necessary to use an iterative method to obtain a sequence of mode solutions.

The mode approximation procedure has been used [31] to examine a strain-rate sensitive fully-clamped circular plate undergoing large transverse deflections. The plate was assumed to have a sandwich cross section and to be made of a homogeneous viscous material. The iterative solution procedure required five to ten cycles to achieve no more than a five percent difference between two successive iterations of the midpoint velocity at a given time. This numerical procedure was repeated at about 13 time steps to generate theoretical estimates for the final permanent transverse displacements [31]. The various approximations in the theoretical procedure are conservative in the sense that they should lead to overestimates of the transverse displacements. However, the theoretical predictions were below corresponding experimental results [37-39]. Various reasons for the discrepancy have been suggested [31].

[1] In some earlier work these were called stationary mode forms.

The mode approximation technique has also been used [32] to study the dynamic behavior of circular plates subjected to axisymmetric pressure pulses when geometric changes were disregarded; i.e., infinitesimal displacements. Stationary mode solutions existed only for impulsive loadings or when the shape of the external pressure distribution was the same as the modal shape of the transverse displacement field.

Bodner and Symonds [40, 41] recently presented experimental results of a test program conducted on strain rate sensitive frames and fully-clamped circular plates subjected to impulsive velocities that produced large permanent displacements. The experimental results were compared [42, 43] with theoretical predictions of the displacement bound and mode approximation methods [30].

The upper bound theorem [29, 30] and the mode approximation technique [31, 32] were considerably more difficult than simple, rigid, perfectly plastic methods and the comparatively simple procedure used to assess the influence of finite displacements [1, 14]. However, the upper bound theorem and the mode approximation technique are useful in that they provide some information about certain features of the structural response that would be much more expensive if a numerical procedure were involved. More importantly, perhaps, the methods provide insight into some characteristics of plastic structural dynamics.

Ploch and Wierzbicki [44] constructed an alternative theorem for obtaining upper bounds on the permanent displacements of impulsively-loaded rigid perfectly-plastic structures with large displacements. The theorem predicted reasonable values for the maximum permanent transverse displacements of a fully-clamped beam subjected to a uniformly distributed impulsive velocity field.

The fundamental characteristics of dynamic plastic mode solutions for structures that undergo infinitesimal displacements have been examined from a variational viewpoint [45-47]. Erkhov [45] studied the dynamic plastic behavior of a simply-supported rigid perfectly-plastic shallow cap subjected to a uniformly distributed pressure with a rectangular pressure-time history. Erkhov's theoretical results for the permanent displacement profile for intermediate pressures were identical to the theoretical solution [48] except for a difference in the static collapse pressures; the difference is related to the use of different yield criteria. A two-degrees-of-freedom system [46] and a simply-supported circular plate [47] have also been examined.

Wierzbicki [49] developed a simplified strain-rate sensitive constitutive relation and demonstrated that an eigenfunction expansion method could be employed to examine the dynamic behavior of plastic continua when the displacements remained infinitesimal.

Maier and Corradi [50] derived an upper bound theorem for the dynamic infinitesimal displacements of elastic-plastic continua using the principle of virtual work and Drucker's stability postulate. The final form of this theorem contains quantities that are either known when motion begins or are related to a solution of the same dynamic problem considered wholly elastic.

RAPIDLY HEATED STRUCTURES

Large neutron pulses can cause a temperature gradient to develop through the thickness of a structure made from a fissionable material. This temperature gradient can cause curvature changes in such structural members as beams, plates and shells as well as other effects. The structural response is governed by dynamics equations when these curvature changes develop in a sufficiently short time. The dynamic structural response can thus be estimated with rigid-plastic analytical methods when the temperature accelerations are sufficiently large.

Parkes [51] examined the dynamic infinitesimal displacement response of a free rigid-plastic beam subjected to a time-dependent and spatially-independent thermal curvature (χ_T). The behavior of the beam depended on the speed of heating (or $\ddot{\chi}_T$). A free beam remained rigid [2] for sufficiently small values of $\ddot{\chi}_T$; at higher values a discrete plastic hinge developed and became an expanding and contracting plastic hinge (zone) at still larger values of $\ddot{\chi}_T$.

The behavior of a free beam having a temperature-independent plastic moment and subjected to an

[2] The beam deforms due to the thermal curvature χ_T, but the associated maximum bending moment is less than the fully plastic bending moment

$\ddot{\chi}_T$ with a sinusoidal[3] temporal form [51] is complicated. For example, the earliest dynamic response associated with a large value of $\ddot{\chi}_T$ is a rigid phase; this is followed by a phase with a positive central plastic hinge. An expanding positive plastic hinge (zone) then develops, followed by three additional phases: a positive central plastic hinge, a contracting plastic hinge, and a negative central plastic hinge. Finally, a rigid phase develops before motion ceases. The sequence of events depends on the magnitude of $\ddot{\chi}_T$ and is undoubtedly also a function of the form of $\ddot{\chi}_T$. The latter has not yet been explored, however.

In a more recent publication, Parkes [52] examined the dynamic rigid-plastic behavior of a rapidly heated cantilever beam subjected to the form of $\ddot{\chi}_T$ considered before [51]. The exact theoretical solution was complicated, even though the displacements remained infinitesimal and the plastic moment was temperature independent. Parkes [52] found that the approximate theoretical analysis of a so-called strong beam -- having all deformation restricted in a hinge at the root of a cantilever -- was much simpler. In addition, the analysis predicted surprisingly accurate values for the final displacements after the relief of the thermal curvature.

Wisniewski [53] examined the dynamic structural behavior of an aluminum 6061 T6 rectangular plate subjected to an X-ray deposition. When the entire surface of the plate exposed to the X-ray deposition is heated almost simultaneously to high temperatures, some of the material melts and blows off. The blow-off creates an impulsive load, which creates a stress wave that propagates through the plate toward the rear surface. Simultaneously, the material below the exposed surface is heated, inducing a compressive stress wave that is reflected as a rarefaction tensile wave from the rear surface. The possibliity of spalling for sufficiently large stresses should therefore be considered in such studies.

Wisniewski [53] simplified the problem described above and used an available computer program to predict the behavior of the material during the first few microseconds of the response. The numerical predictions were used to generate the input for an elastic-plastic finite-difference scheme [54] for predicting the structural response, the duration of which is in milliseconds [1].

FLUID-STRUCTURE INTERACTION

In a recent review [55] Krajcinovic distinguished between steady-state and transient behavior of structures interacting with a fluid and discussed the general features of transient interaction problems involving constant and variable wetted surfaces. The theoretical behavior of a transient interaction problem is simplified considerably when the structural material is idealized as rigid-plastic. The theoretical predictions of such analyses are useful when the ultimate performance of a structure is of primary concern, provided the usual restrictions associated with such an approximation are satisfied [1-4, 55].

Krajcinovic [56] examined the dynamic response of a simply-supported rigid-plastic beam resting on a semi-infinite pool of incompressible, irrotational, and inviscid fluid. The governing equations were formulated for a beam subjected to a time-dependent external pressure that caused infinitesimal transverse displacements. Evaluation of the fluid back pressure and the virtual mass associated with a simple triangular deformation mode for the beam without any traveling hinges was the most difficult task. Krajcinovic also examined a simply-supported beam subjected to a uniformly distributed pressure and found that a single mode transverse deformation profile was valid so long as the magnitude of the external dynamic pressure was less than about three times the corresponding static collapse pressure [56]. The permanent transverse displacements were less than those that would be obtained in vacuo.

Krajcinovic [57] also examined the dynamic behavior of a simply-supported, circular, rigid, perfectly plastic plate resting on a potential fluid. The response due to a uniformly distributed external pressure with a rectangular-shaped pressure time history was obtained for a conical transverse displacement profile. A conical displacement profile could be used for external pressure pulses with magnitudes up to somewhat more than twice[4] the corresponding static collapse pressure. The theoretical predictions for the impulsive velocity loading case were also presented [57]. However, these results are of doubtful validity until it has been established that a statically admissible generalized stress field can be associated with a conical displacement profile. It is unlikely that the association can be established, however, because it is known

[3] **This form is characteristic of neutron heating in a pulsed reactor**

[4] **Equation 60 [57] gives a ratio of 2 when in vacuo and 2.346 for a steel plate with a radius to thickness ratio of 25 resting on water**

that traveling plastic hinges develop during the response of the same problem in vacuo.

From the work reported [56, 57], it can be concluded that external dynamic pressures must be low -- only a few times larger than corresponding static collapse pressures -- because larger external pressures would probably give rise to traveling plastic hinges that would complicate the calculation of the fluid back pressure and virtual mass.

The nonlinear influence of finite transverse displacements, or geometric changes, would have an important effect on the response when maximum permanent transverse displacements exceeded the corresponding structural thickness. These effects have been discussed [1, 14] for beams and plates in vacuo and exposed to dynamic loads on one surface. Theoretical results [58] illustrate the important strengthening influence of membrane forces that developed in a simply-supported circular plate subjected to a static pressure distributed over the entire surface of one side and another static pressure distributed within a circular region on the opposite surface.

Theoretical solutions [56, 57] have been simplified by neglecting the generation of waves on the surface of the fluid. However, in a practical beam or plate problem involving a single mode transverse deformation profile, it is inevitable that waves would be generated on the fluid surface outside the supports when the fluid is assumed incompressible. Nevertheless, it is possible to retain the incompressibility assumption without generating surface waves by using more complex transverse displacement fields; e.g., a modification of the third modal velocity fields [13, 15].

Duffey [59] examined the transient response of visco-plastic spherical shells submerged in a fluid. The inner surface of a shell was subjected to a spherically symmetric impulsive velocity that produced a spherically symmetric structural response. Duffey considered the inviscid fluid to be compressible and used the classical wave equation to evaluate the fluid pressure. The thickness of the shell was assumed to be sufficiently thin so that the material in the entire shell could pass simultaneously from an elastic to a plastic state. With these simplifications, Duffey was able to examine the influence of material elasticity (including unloading), material strain hardening, and material strain rate sensitivity. One interesting conclusion was that a significant error is associated with the linearization of the strain rate sensitive relations.

Theoretical solutions [56, 57, 59] have been developed for structures with one side dynamically loaded and the other side in contact with a fluid; an example would be an internal explosion in the hull of a ship. Structures are sometimes subjected to a disturbance that travels through a fluid from a distant source; for example, external explosion acting on the hull of a ship [60]. Other types of practical problems might involve the impact of a structure on a fluid, as the slamming of ships and marine vehicles; or the impact of a fluid on a structure, as the water wave impact on a barrier or offshore platform. Simple rigid-plastic methods developed [61-63] to estimate the damage sustained by ships and marine vehicles from severe slamming and bow impacts were in surprisingly good agreement with experimental results. The theoretical methods could be developed further to examine other problems.

DYNAMIC PLASTIC BUCKLING

The work described in the previous sections has to do with the inelastic behavior of structures that have a stable response when subjected to dynamic loads. However, dynamic plastic buckling, or unstable behavior -- which is characterized by wrinkling, as in static buckling -- can occur when certain structures are acted on by large external loads.

A brief literature review of the dynamic plastic buckling of rods, flat plates, cylindrical shells, and spherical shells has been presented [1]. It would appear that the dynamic plastic instability of all structural problems investigated thus far occurs as a result of the growth of small imperfections in otherwise uniform initial displacement and velocity fields. Unlike classical static buckling analyses, no distinct value of the dynamic load that causes structural instability is predicted by theoretical analyses. Rather, the results obtained indicate the way in which the displacement profile of a structure increases with time for different dynamic load levels. Buckling is said to occur when the dynamic load reaches a threshold, or critical, value; this value is associated with the minimum unacceptable or maximum acceptable deformation, the magnitude of which is defined arbitrarily.

The dynamic plastic buckling of a cylindrical shell made from a rigid linear strain-hardening material and subjected to a uniformly distributed, almost axisymmetric, external impulsive velocity field has been examined [64]. An especially simple solution for an infinitely long cylindrical shell allowed various characteristics of the response to be examined analytically. For example, the dynamic plastic buckling of a long cylindrical shell was more sensitive to initial imperfections in the profile than to imperfections in the initial velocity field. This is fortuitous because it is usually easier to control imperfections in the initial shape than imperfections in the initial velocity field. Moreover, the greatest amount of scatter might be expected in the experimental critical mode numbers of long cylindrical shells with large radius to thickness ratios and/or small values of the material parameter β_1, the ratio of tangent modulus to average flow stress [64]. Furthermore, local elastic unloading is more likely to occur for shells with the larger radius to thickness ratios and/or smaller values of the material parameter β_1 [64].

The theoretical predictions for the dominant behavior, critical mode numbers, and threshold impulses from all known previous studies on the dynamic plastic buckling of cylindrical shells and rings subjected to external impulsive velocities have been summarized [64]. In addition, experimental results were presented from a test program on hot-rolled mild steel and aluminum 6061 T6 rings subjected to axisymmetric external impulsive velocity fields. The experimental values were compared with all known experimental results and with theoretical predictions for the dynamic plastic buckling of rings and cylindrical shells. The various theoretical predictions were widely divergent: some were in good agreement with corresponding experimental values, but others were not.

Simple theoretical predictions for the permanent radial displacements of rigid perfectly plastic rings subjected to an axisymmetric velocity field (equations (28) and (33) in [64]) generally agree reasonably well with the permanent average radial displacement recorded in the experimental tests, provided any material strain rate sensitivity is accounted for, as has been suggested [65] and demonstrated for shells [66].

The critical mode numbers observed during tests have been compared [64] with the results of all known relevant experimental investigations. The results were reasonably consistent, notwithstanding the differences in yield stresses of the materials, experimental techniques, and the fact that the buckled profiles of cylindrical shells and rings are irregular. The experimental critical mode numbers typically increase with an increase in the length to radius ratio and with an increase in the radius to thickness ratio.

Experimental results [64] indicated that the estimated threshold impulses [67] (equation (49) in [64]) assures that permanent wrinkles in the deformed profiles of the rings will remain small. However, experimental results [64] demonstrated that the ratio of wrinkle (buckle) amplitude to average permanent radial displacement decreases as the impulse magnitude increases.

The manner in which initial geometric imperfections of the rings influences the wrinkle amplitude has been explored [64].

The general features of iso-damage curves in a dimensionless peak load-impulse space have been discussed [68]. Such curves were convenient for representing theoretical predictions and experimental results on the dynamic response of various structures subjected to pulse loads (as distinct from oscillatory loads). Moreover, an iso-damage curve for the dynamic buckling of a simply-supported cylindrical shell under uniform lateral pulse loads is not very sensitive to the amplification factor -- that is, the factor by which initial imperfections grow during the response -- or to the pulse shape. Iso-damage curves have also been plotted [68] for the dynamic plastic response of beams and circular plates subjected to the transverse dynamic loads responsible for stable behavior and infinitesimal displacements. Iso-damage curves presented [62] for rectangular plates retained the influence of finite transverse displacements, or geometric changes.

Florence and Abrahamson [69] observed that the stability of cylindrical shells and rings subjected to large external impulsive velocities improved during deformation when the increase in wall thickness was taken into account. They defined a critical impulsive velocity that is associated with a specified acceptable amplification factor. Impulsive velocities larger than the critical value thus produce acceptable departures from the circularity of a cylindrical shell; impulsive velocities smaller than the critical value are responsible for unacceptable damage. The general trend of experimental results [64] indicates that the ratio of the wrinkle (buckle) amplitude to the average permanent radial displacement of a ring decreases as the impulse increases.

The governing equations for a ring made from a rigid linear visco-plastic material have been formulated and used to study the case in which the impulsive velocity remains constant during the collapse of a cylindrical shell onto its longitudinal axis [69]. The governing equations were solved numerically; the results indicated that linear visco-plasticity drastically reduced the amplification factors and the preferred mode numbers, thereby contributing to the stability of a cylindrical shell.

Lee [70] explored the bifurcation and uniqueness of elastic-plastic continua loaded dynamically from a fundamental viewpoint because random initial imperfections, or perturbed motion, may be insufficient to describe the dynamic plastic buckling of some structures. Lee also developed a quasi-bifurcation criterion for the stability of elastic-plastic continua loaded dynamically [71]. A quasi-bifurcation of motion develops at a time t_{cr} when a nontrivial perturbed motion exists. No applications of this theorem have yet been published, but Lee claims to have successfully used it to describe the dynamic plastic buckling of rods subjected to axial loads. Lee showed that his dynamic quasi-bifurcation criterion reduces to

REFERENCES

1. Jones, N., "A Literature Review of the Dynamic Plastic Response of Structures," Shock Vib. Dig., 7 (8), pp 89-105 (1975).

2. Krajcinovic, D., "Dynamic Response of Rigid Ideally Plastic Structures," Shock Vib. Dig., 5 (2), pp 2-9 (1973).

3. Baker, W.E., "Approximate Techniques for Plastic Deformation of Structures under Impulsive Loading," Shock Vib. Dig., 7 (7), pp 107-117 (1975).

4. Rawlings, B., "Response of Structures to Dynamic Loads," Mechanical Properties at High Rates of Strain, J. Harding, Ed., Inst. Physics (London), Conf. Ser. No. 21, pp 279-298 (1974).

5. Spencer, A.J.M., "Deformations of Fibre-Reinforced Materials," Clarendon Press (1972).

6. Spencer, A.J.M., "Dynamics of Ideal Fibre-Reinforced Rigid-Plastic Beams," J. Mech. Phys. Solids, 22, pp 147-159 (1974).

7. Jones, N., "Dynamic Behavior of Ideal Fibre-Reinforced Rigid-Plastic Beams," J. Appl. Mech., Trans. ASME, 43 (2), pp 319-324 (1976).

8. Spencer, A.J.M., "A Note on an Ideal Fibre-Reinforced Rigid-Plastic Beam Brought to Rest by Transverse Impact," Mech. Res. Comm., 3, pp 55-58 (1976).

9. Laudiero, F. and Jones, N., "Impulsive Loading of an Ideal Fibre-Reinforced Rigid-Plastic Beam," J. Struc. Mech., 5 (4), pp 369-382 (1977).

10. Shaw, L. and Spencer, A.J.M., "Impulsive Loading of Ideal Fibre-Reinforced Rigid-Plastic Beams," Parts I-III, Intl. J. Solids Struc., 13, pp 823-854 (1977).

11. Chon, C.T. and Martin, J.B., "A Rationalization of Mode Approximations for Dynamically Loaded Rigid-Plastic Structures Based on a Simple Model," J. Struc. Mech., 4 (1), pp 1-31 (1976).

12. Symonds, P.S. and Wierzbicki, T., "On an Extremum Principle for Mode Form Solutions in Plastic Structural Dynamics," J. Appl. Mech., Trans. ASME, 42 (3), pp 630-640 (1975).

13. Jones, N. and Wierzbicki, T., "A Study of the Higher Modal Dynamic Plastic Response of Beams," Intl. J. Mech. Sci., 18, pp 533-542 (1976).

14. Jones, N., "A Theoretical Study of the Dynamic Plastic Behavior of Beams and Plates with Finite-

Deflections," Intl. J. Solids Struc., 7, pp 1007-1029 (1971).

15. Jones, N. and Guedes Soares, C., "Higher Modal Dynamic Plastic Behavior of Beams Loaded Impulsively," Intl. J. Mech. Sci., 20, p 135 (1978).

16. Wu, R.W.-H. and Witmer, E.A., "Computer Program - JET 3 to Calculate the Large Elastic-Plastic Dynamically-Induced Deformations of Free and Restrained, Partial and/or Complete Structural Rings," NASA Tech. Rept. CR-120-993 (1972).

17. Wu, R.W.-H. and Witmer, E.A., "Nonlinear Transient Responses of Structures by the Spatial Finite-Element Method," AIAA J., 11, pp 1110-1117 (1973).

18. Jones, N., "Plastic Failure of Ductile Beams Loaded Dynamically," J. Engr. Indus., Trans. ASME, 98 (1), pp 131-136 (1976).

19. Symonds, P.S., "Plastic Shear Deformations in Dynamic Load Problems," Engineering Plasticity, J. Heyman and F.A. Leckie, C.U.P., Eds., pp 647-664 (1968).

20. Menkes, S.B. and Opat, H.J., "Broken Beams," Exptl. Mech., 13, pp 480-486 (1973).

21. Heyman, J., "The Full Plastic Moment of an I-Beam in the Presence of Shear Force," J. Mech. Phys. Solids, 18, pp 359-365 (1970).

22. Gomes de Oliveira, J. and Jones, N., "Some Remarks on the Influence of Transverse Shear on the Plastic Yielding of Structures," MIT Dept. Ocean Engrg., Rept. 77-17 (1977).

23. Hodge, P.G., "Interaction Curves for Shear and Bending of Plastic Beams," J. Appl. Mech., Trans. ASME, 24 (3), pp 453-456 (1957).

24. Ranshi, A.S., Chitkara, N.R., and Johnson, W., "Plastic Yielding of I-Beams under Shear, and Shear and Axial Loading," Intl. J. Mech. Sci., 18, pp 375-385 (1976).

25. Nonaka, T., "Shear and Bending Response of a Rigid-Plastic Beam to Blast-Type Loading," Ing.-Arch., 46, pp 35-52 (1977).

26. Jones, N. and Gomes de Oliveira, J., "The Influence of Rotatory Inertia and Transverse Shear on the Dynamic Plastic Behavior of Beams," MIT Dept. Ocean Engrg., Rept. 77-18 (1977).

27. Gomes de Oliveira, J. and Jones, N., "A Numerical Procedure for the Dynamic Plastic Response of Beams with Rotatory Inertia and Transverse Shear Effects," MIT Dept. Ocean Engrg., Rept. 78-2 (1978).

28. Symonds, P.S., "Approximation Techniques for Impulsively Loaded Structures of Rate Sensitive Plastic Behavior," SIAM J. Appl. Math., 25 (3), pp 462-473 (1973).

29. Symonds, P.S. and Chon, C.T., "Bounds for Finite-Deflections of Impulsively Loaded Structures with Time-Dependent Plastic Behavior," Intl. J. Solids Struc., 11, pp 403-423 (1975).

30. Symonds, P.S. and Chon, C.T., "Approximation Techniques for Impulsive Loading of Structures of Time-Dependent Plastic Behavior with Finite-Deflections," Mechanical Properties at High Rates of Strain, J. Harding, Ed., Inst. Physics (London), Conf. Ser. No. 21, pp 299-316 (1974).

31. Chon, C.T. and Symonds, P.S., "Large Dynamic Plastic Deflection of Plates by Mode Method," ASCE J. Engr. Mech. Div., 103 (EM1), pp 169-187 (1977).

32. Symonds, P.S. and Chon, C.T., "On Dynamic Plastic Mode Form Solutions," Brown Univ., Rept. N00014-0860/2 (June 1977).

33. Ponter, A.R.S., "An Energy Theorem for Time Dependent Materials," J. Mech. Phys. Solids, 17, pp 63-71 (1969).

34. Martin, J.B., "Impulsive Loading Theorems for Rigid-Plastic Continua," ASCE J. Engr. Mech. Div., 90 (EM5), pp 27-42 (1964).

35. Symonds, P.S. and Jones, N., "Impulsive Loading of Fully Clamped Beams with Finite Plastic Deflections and Strain Rate Sensitivity," Intl. J. Mech. Sci., 14, pp 49-69 (1972).

36. Martin, J.B. and Symonds, P.S., "Mode Approximations for Impulsively Loaded Rigid-Plastic Structures," ASCE J. Engr. Mech. Div., 92 (EM5), pp 43-66 (1966).

37. Wierzbicki, T. and Florence, A.L., "A Theoretical and Experimental Investigation of Impulsively Loaded Clamped Circular Viscoplastic Plates," Intl. J. Solids Struc., 6, pp 553-568 (1970).

38. Witmer, E.A., Merlis, F., and Pirotin, S.D., "Experimental Studies of Explosively-Induced Large Deformations of Flat Circular 2024-0 Aluminum Plates with Clamped Edges and of Free Thin Cylindrical 6061-T6 Shells," MIT Dept. Aeronaut. Astronaut., Rept. No. 134, ASRL TR 152-5 (1974).

39. Duffey, T.A. and Key, S.W., "Experimental-Theoretical Correlations of Impulsively Loaded Clamped Circular Plates," Exptl. Mech., 9, pp 241-249 (1969).

40. Bodner, S.R. and Symonds, P.S., "Experiments on Dynamic Plastic Loading of Frames," Brown Univ., Rept. N00014-0860/4 (July 1977).

41. Bodner, S.R. and Symonds, P.S., "Experiments on Viscoplastic Response of Circular Plates to Impulsive Loading," Brown Univ., Rept. N000-14-0860/6 (July 1977).

42. Symonds, P.S. and Chon, C.T., "Large Viscoplastic Deflections of Impulsively Loaded Plane Frames," Brown Univ., Rept. N00014-0860/3 (Sept 1977).

43. Symonds, P.S. and Chon, C.T., "Finite Viscoplastic Deflections of an Impulsively Loaded Plate by the Mode Approximation Technique," Brown Univ., Rept. N00014-0860/5 (Sept 1977).

44. Ploch, J. and Wierzbicki, T., "Oszacowania Duzych Niesprezystych Deformacji Dynamicznie Obciazonych Konstrukcji," Politech. Rzeszowska Im. Ignacego Lukasiewicza, 111 Symposium Dynamiki i Statecznosci Konstrukcji, Rzeszow, pazdziernik, pp 121-130 (1976) (In Polish).

45. Erkhov, M.I., "Extremum Principles in the Dynamics of Rigid-Plastic Bodies and Mathematical Programming," Archives of Mechanics, 25 (1), pp 69-86 (1973).

46. Symonds, P.S. and Wierzbicki, T., "On an Extremum Principle for Mode Form Solutions in Plastic Structural Dynamics," J. Appl. Mech., Trans. ASME, 42 (3), pp 630-640 (1975).

47. Wierzbicki, T., "Direct Variational Approach to Dynamic Plastic Mode Solutions," Bull. de L'Acad. Polonaise des Sciences, Series des Sci. Tech., 23 (6), pp 299-305 (1975).

48. Ich, N.T. and Jones, N., "The Dynamic Plastic Behavior of Simply Supported Spherical Shells," Intl. J. Solids Struc., 9, pp 741-760 (1973).

49. Wierzbicki, T., "Application of an Eigenfunction Expansion Method in Plasticity," J. Appl. Mech., Trans. ASME, 41 (2), pp 448-452 (1974).

50. Maier, G. and Corradi, L., "Upper Bounds on Dynamic Deformations of Elastoplastic Continua," Meccanica, 9 (1), pp 30-35 (1974).

51. Parkes, E.W., "The Expanding and Contracting Hinge in a Rapidly Heated Rigid-Plastic Beam," Royal Soc. London, Proc., Ser. A, 337, pp 351-364 (1974).

52. Parkes, E.W., "The Rapidly Heated Rigid-Plastic Cantilever," Private Commun. (1977).

53. Wisniewski, H.L., "Coupling of X-Ray Deposition to Structural Response," Ballistic Res. Lab., Aberdeen, MD, Memo, Rept. No. 2761 (June 1977).

54. Atluri, S., Witmer, E.A., Leech, J.W., and Morino, L., "PETROS 3: A Finite Difference Method and Program for the Calculation of Large Elastic-Plastic Dynamically-Induced Deformations of Multilayer Variable-Thickness Shells," U.S. Army Ballistic Res. Lab., Contract Rept. No. 60 (Nov 1971).

55. Krajcinovic, D., "Some Transient Problems of Structures Interacting with Fluid," Shock Vib. Dig., 9 (9), pp 9-16 (1977).

56. Krajcinovic, D., "Dynamic Plastic Response of Beams Resting on Fluid," Intl. J. Solids Struc., 11, pp 1235-1243 (1975).

57. Krajcinovic, D., "Dynamic Response of Circular Rigid-Plastic Plates Resting on Fluid," J. Appl. Mech., Trans. ASME, 43 (1), pp 102-106 (1976).

58. Jones, N., "Combined Distributed Loads on Rigid Plastic Circular Plates with Large Deflections," Intl. J. Solids Struc., 5, pp 51-64 (1969).

59. Duffey, T.A., "Transient Response of Viscoplastic and Viscoelastic Shells Submerged in Fluid Media," J. Appl. Mech., Trans. ASME, 43 (1), pp 137-143 (1976).

60. Oleson, M.W. and Belsheim, R.O., "Shipboard Shock Environment and Its Measurement," Shock Vib. Dig., 9 (12), pp 3-12 (1977).

61. Jones, N., "Slamming Damage," J. Ship Res., 17 (2), pp 80-86 (1973).

62. Jones, N., "Plastic Behavior of Ship Structures," Soc. Naval Arch. Mar. Engr., Trans., 84, pp 115-145 (1976).

63. Jones, N., "Damage Estimates for Plating of Ships and Marine Vehicles," Intl. Symp. Practical Design in Shipbuilding (PRADS), Soc. Naval Arch. Japan, pp 121-128 (1977).

64. Jones, N. and Okawa, D.M., "Dynamic Plastic Buckling of Rings and Cylindrical Shells," Nucl. Engr. Des., 37, pp 125-147 (1976).

65. Perrone, N., "On a Simplified Method for Solving Impulsively Loaded Structures of Rate-Sensitive Materials," J. Appl. Mech., Trans. ASME, 32, pp 489-492 (1965).

66. Jones, N., "Some Remarks on the Strain-Rate Sensitive Behavior of Shells," Problems of Elasticity, A. Sawczuk, Ed., Noordhoff, Vol. 2, pp 403-407 (1974).

67. Florence, A.L. and Vaughan, H., "Dynamic Plastic Flow Buckling of Short Cylindrical Shells due to Impulsive Loading," Intl. J. Solids Struc., 4, pp 741-756 (1968).

68. Abrahamson, G.R. and Lindberg, H.E., "Peak Load-Impulse Characterization of Critical Pulse Loads in Structural Dynamics," Nucl. Engr. Des., 37, pp 35-46 (1976).

69. Florence, A.L. and Abrahamson, G.R., "Critical Velocity for Collapse of Viscoplastic Cylindrical Shells without Buckling," J. Appl. Mech., Trans. ASME, 44 (1), pp 89-94 (1977).

70. Lee, L.H.N., "Bifurcation and Uniqueness in Dynamics of Elastic-Plastic Continua," Intl. J. Engr. Sci., 13 (1), pp 69-76 (1975).

71. Lee, L.H.N., "Quasi-Bifurcation in Dynamics of Elastic-Plastic Continua," J. Appl. Mech., Trans. ASME, 44 (3), pp 413-418 (1977).

BOOK REVIEWS

NUMERICAL METHODS IN FINITE ELEMENT ANALYSIS

K.-J. Bathe and E.L. Wilson
Prentice-Hall, Inc, Englewood Cliffs, NJ

Numerous books on finite element analysis have appeared in the last few years; this book is one of the better ones. Written by the developers of SAP (Structural Analysis Program) finite element computer programs, the book consists of 12 chapters divided into three sections.

Chapters I and II introduce matrix methods, beginning with simple operations and progressing to vector spaces and subspaces, matrix representation of linear transformations, and an introduction to variational formulations. The chapter concludes with eigenvalue solutions of a symmetrical matrix, the Rayleigh quotient, and vector and matrix norms.

Chapters III and IV contain a basic formulation of the finite element method and an introduction to beam and plate (plane stress) elements, plate bending elements, and three-dimensional solid elements. A good discussion of convergence requirements leads to a description of generalized coordinate finite element models. In the formulation of isoparametric elements, the authors derive the basics and proceed from two-dimensional to more complicated three-dimensional elements. Gauss points and Jacobian matrices are explained, as is their role in isoparametric relationships. The chapter concludes with numerical integration methods used to solve the integrals employed in isoparametric relations. The reviewer would have liked to have seen more applications of interpolation formulas for the higher order 20 node solid element.

Early finite element work involved variational formulation. The authors recapture this aspect in Chapter V and show its relationship to the Rayleigh-Ritz method. The chapter includes a formulation of heat transfer analysis and nonconforming displacement-based finite elements. Other formulations of finite elements, including hybrid and mixed models, are considered. It is the reviewer's opinion that the Galerkin variational approach should have been included.

Chapter VI resembles a manual on using a finite element program. Lists for static analysis programs and flow charts are included as introductory material to more advanced sections.

Chapter VII concerns the use of various modern methods of analysis to solve large problems. The Gauss elimination, Choleskey method, Givens method, Householder's method, and the Gauss-Seidel iteration solution required for static analysis are described.

Chapter VIII describes the direct integration methods (Houbolt, Wilson, or Newmark) used to solve the more difficult dynamic problems. Although the content is sometimes difficult to understand, the explanations are clear. The chapter concludes with mode superpositions.

In Chapters IX and X direct integration methods are applied; their shortcomings and their accuracy are reviewed. The important eignevalue solutions, which are important in cutting computer costs, are presented, as are common methods of mass normalization, static condensation of nodes, and approximate methods. The chapter concludes with a brief discussion of component mode synthesis.

Chapters XI and XII consider the vector iteration method and its variants, as well as transformation methods namely, the Jacobi, Sturm sequence property, and the Householder Q R iteration method. The large eigensolution requires special methods, and the authors describe the determinant search and subspace iteration.

This is an excellent book, with clearly written explanations and computer programs. The careful reading required is well worth the effort. The reviewer heartily recommends this book to both beginners and those with experience. It should be on the desk of anyone involved in finite element analysis.

Herb Saunders
General Electric Co. LSTGD
Schenectady, NY 12345

ELASTODYNAMICS
VOLUME I. FINITE MOTIONS

A. Cemal Eringen and E.S. Şuhubi
Academic Press, New York and London, 1974

This is the first of a two-volume set on the dynamics of elastic continua, "intended, hopefully, to remedy the need for a rigourous study of the mathematical theory of elastodynamics." Volume I consists of four chapters and two appendices as follows:

- I. Basic Theory
- II. Propagation of Singular Surfaces
- III. Finite Motion of Elastic Bodies
- IV. Small Motions Superimposed on Large Static Deformations
- A. Tensor Analysis
- B. Quasilinear System of Hyperbolic Equations with Two Independent Variables

Chapter I provides the reader unacquainted with a modern treatment of the mechanics of continua a concise, readable exposure to kinematics, balance principles, and constitutive equations for thermoelastic solids. A rectangular Cartesian reference system is employed; with the aid of Appendix A, the results can be expressed in curvilinear coordinates when needed. Field equations are obtained for finite motion of nonlinear elastic solids and specialized to linear and quadratic approximate theories.

Chapter II introduces the geometry and fundamental jump conditions relevant to moving singular surfaces (discontinuity surfaces) in materials. The singular surfaces associated with motion of a material body, dynamical compatibility conditions, and the classification of singular surfaces are treated. Both shock waves and acceleration waves (sound waves) are discussed for elastic bodies, with specialization for acceleration waves in isotropic, as well as incompressible, materials.

Chapter III is devoted to the solution of a collection of problems associated with finite motions of elastic solids. First, two examples of quasi-equilibrated, controllable motions are presented: radial oscillations of a cylindrical tube and radial oscillations of a spherical shell. These results obtain for an isotropic, incompressible elastic material. The notion of simple waves in nonlinear elastic bodies (resembling and generalizing plane waves in linear elastic solids) is developed and illustrated in the remainder of the Chapter. As an example, material found in Appendix B is used to discuss the Riemann problem for a isotropic elastic half-space and to bring out the concepts of longitudinal and shear waves in nonlinear elastic solids.

In Chapter IV, equations necessary to examine small motions superimposed on large static deformation of an elastic body are developed. This material finds application in the study of the stability of motion, as well as in numerical analysis of finite motion of bodies.

A substantial amount of the material presented in the book appears in two earlier works of the first author. Repetition presumably serves to make this volume self-contained.

The design engineer requiring knowledge of finite wave motion in nonlinear elastic materials will find little consolation in the authors' observation that the field is still "barren." Although this book is a step in the direction of building the foundation on which rational design will ultimately be based, it will be clear to the reader that rational solutions to the real world problems enunciated in the preface remain a dream.

Karl S. Pister
Professor of Engineering Science
University of California, Berkeley
Berkeley, CA 94720

SYMPOSIUM ON RAILROAD EQUIPMENT DYNAMICS

R. Byrne, Editor

The American Society of Mechanical Engineers, 1976

This volume is a collection of eight papers presented at the Joint ASME-IEEE *Railroad Conference in* April, 1976. It is a sample of current analysis, testing, and design techniques for improving the dynamic performance of rail vehicles and components. Vehicle vibration is the principal, though not exclusive, concern of the papers. Although there is no formal division, three distinct types of articles are included.

The first type emphasizes mathematical modeling and data analysis. In the first paper, Scheffel defines the conflicting demands of lateral stability and curving performance on suspension and wheel profile characteristics. Using simple mathematical and laboratory wheelset models, he indicates the importance of wheel wear to limiting dynamic behavior. The possibility of substantial improvement in both hunting and curving with cross-braced truck designs is discussed and demonstrated with field test results.

Garg, Chu, and Mels focus on the area of lateral dynamic stability. They illustrate the use of linear models for parametric studies of suspension characteristics. A model of a specific four axle vehicle is used to indicate the sensitivity to, as well as interaction suspension, wheel profile, and creep parameters on linear critical hunting speeds.

Cooperrider, Law, et al present their method for characterization of the nonlinear variation of wheel/rail profiles as a function of lateral displacement. They establish a correlation between their analytical and experimental procedures and present a sample of their results for specific profiles. The form of the results provides a description of such parameters as conicity and gravitational stiffness; such parameters determine the limits of dynamic performance in analytical models of rail vehicles. The authors and others have reported such studies in recent work.

Guins, in the last paper of this group, uses random vibration techniques to analyze freight car ride data. He emphasizes the importance of spectral analysis hardware in power spectral density characterization of the vibration environment. In particular, he examines the relation of track irregularities to vertical car acceleration and establishes the predominance of joint frequency on this vibration for the test results considered.

The three papers in the second group of articles examine specific problems associated with the demanding conditions of coal hauling unit train operation. Each article discusses the road and laboratory tests used to identify and investigate the causes of the problems and describes the design modifications that provided the engineering fixes in each case. Weber and Driver describe their investigation of cracks in truck bolsters. Their fatigue analysis, coordinated with the test program, revealed the need for heavier structure to assure lower stress levels for the severe dynamic environment in the service expected of the unit train vehicles. Rhine, Williams, and Driver, in a short article on corrosion fatigue of car bodies and a longer one on Brinelling of roller bearings during impact operations, describe the successful use of strain gage instrumented components to diagnose and relieve problems. In each case, the need to properly characterize extreme loading, lading, and operating conditions in relation to design specifications is clearly identified.

The last paper, by Isler, Clingerman, and Paternoster, is largely descriptive. It is a report of the design features of a bimodal rapid transit rail passenger car. The constraint of nearly equivalent acceleration performance under gas turbine and conventional DC third rail power emphasize the issue of specifications for propulsion and system operation.

In summary, the volume is a set of examples of the engineering tools that are being applied rather than an exhaustive survey of all features of rail dynamics. It represents a kind of progress report on the increasing awareness of and concern with dynamic environments that set the limits on operating performance. In particular, it provides a useful digest of evolving techniques and identifies the need for further refinement of these tools.

A.B. Perlman
Department of Mechanical Engineering
Tufts University
Medford, MA 02155

ADVANCE PROGRAM

49TH SHOCK AND VIBRATION SYMPOSIUM

October 17-19, 1978

Washington, D.C.

Goddard Space Flight Center
Greenbelt, Maryland
will be your host for this Symposium

THE SHOCK AND VIBRATION
INFORMATION CENTER

GENERAL INFORMATION

CONFERENCE LOCATION: Registration, information, and unclassified technical sessions are at the International Inn, Washington, D.C.

REGISTRATION: All registrants must complete an UNCLASSIFIED Registration Card, which may be obtained from the SVIC, before they may attend the technical session at the International Inn. Advance registration is strongly recommended.

FEE: Registration fee covers the cost of the proceedings of the 49th Shock and Vibration Symposium. There is no fee for SVIC Annual Subscribers and for participants. Since the registration fee covers only the cost of the proceedings, there will be no reduced fee for part time attendance. The schedule of fees is as follows:

Subscriber Registration (for employees of SVIC Annual Subscribers)	No Fee
Participant Registration (Authors, Speakers, Chairmen, Cochairmen)	No Fee
General Registration (All Others)	$60.00

For more information on the Symposium contact:

The Shock and Vibration Information Center
Naval Research Laboratory - Code 8404
Washington, D.C. 20375
Telephone: (202) 767-2220

49TH SYMPOSIUM PROGRAM COMMITTEE

Dr. Eugene Sevin
Defense Nuclear Agency
Washington, D.C. 20305

Mr. Daniel Van Ert
Aerospace Corporation
Los Angeles, California 90045

Mr. Charles Fridenger
Naval Surface Weapons Center
Silver Spring, Maryland 20910

Mr. Brian Keegan
Code 321.0
Structural Dynamics Branch, Test & Evaluation Div.
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. E. Ken Stewart
U.S. Army Armament R&D Command
Dover, New Jersey 07801

SVIC STAFF

Mr. Henry C. Pusey, Director
Mr. Rudolph H. Volin
Dr. J. Gordan Showalter
Mrs. Barbara Szymanski (Secretary)
Mrs. Carol Healey (Secretary)

SHOCK AND VIBRATION INFORMATION CENTER
NAVAL RESEARCH LABORATORY
CODE 8404
WASHINGTON, D.C. 20375

Telephone: (202) 767-2220
Autovon: 297-2220

OPENING SESSION

(Unclassified) 9:00 A.M. Tuesday, October 17

Washington Room

Chairman: Mr. Brian Keegan, NASA Goddard Space Flight Center, Greenbelt, MD

Cochairman: Mr. Henry C. Pusey, Director, Shock and Vibration Information Center, Naval Research Laboratory, Washington, D.C.

Welcome: NASA Goddard Space Flight Center representative

Keynote Address: Mr. Andrew J. Stofan, Deputy Associate Administrator for Space Sciences, National Aeronautics and Space Administration, Washington, D.C.

Invited Papers: "The Role of Dynamics in DoD Science and Technology Program" Dr. George P. Millburn, Office of the Deputy Director of Research and Engineering (Research and Advanced Technology), Washington, D.C.

"Dynamic Problems in Large Space Structures" Dr. Michael Card, Dr. Garnett Horner, and Dr. Ray Montgomery, NASA Langley Research Center, Hampton, VA

"Analytical Model for Predictions of Noise Levels in Space Shuttle Payload Bay" Dr. John F. Wilby and Larry D. Pope, Bolt, Beranek and Newman, Canoga Park, CA

Session IA (Unclassified) 2:00 P.M. Tuesday, October 17

Adams Room

VIBRATION AND ACOUSTICS

Chairman: Mr. Edgar K. Stewart, U.S. Army Armament R&D Command, Dover, NJ

Cochairman: Mr. Larry Cook, NASA, Goddard Space Flight Center, Greenbelt, MD

1. Probability of Failure Prediction for Step-Stress Fatigue Under Sine or Random Stress - R.G. LAMBERT, General Electric Company, Utica, NY

2. Signature Analysis of Inertial Guidance Systems - D.F. SULLIVAN, Charles S. Draper Laboratory, Cambridge, MA

3. Multiple Shaker Transient Waveform Control - P. RADER and R. BERRY, Martin Marietta Corporation, Denver, CO

4. On the Use of Coherence Functions to Evaluate Sources of Dynamic Excitation - S. BARRETT, Martin Marietta Corporation, Denver, CO

BREAK

5. Status of Cavity Noise Phenomena Measurement and Suppression B1 Aircraft - A.G. TIPTON and C.H. HODSON, Rockwell International, Los Angeles, CA

6. Experimental Evaluation of the Effects of Payloads on the Space Shuttle Acoustic Environment Using a 1/4 Scale Dynamic Model - P. RENTZ, A. PIERSOL, W. WOOD, and J. WILBY, Bolt Beranek and Newman, Canoga Park, CA

7. Cavity Noise Induced by Aerodynamic Flow - L.A. SCHUTZENHOFER, P.W. HOWARD, W.W. CLEVER, and S.H. GUEST, NASA, Marshall Space Flight Center, AL

SUPPLEMENTARY

Barkley Dam Gate Vibration Field Tests - E.D. HART and J.E. HITE, Jr., U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS

Session 1B (Unclassified) 2:00 P.M. Tuesday, October 17

Monroe Room

BLAST AND SHOCK

Chairman: Dr. Jimmie P. Balsara, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

Cochairman: Mr. Edward Rzepka, Naval Surface Weapons Center, Silver Spring, MD

1. Snaps in Structures - M. ZAK, Jet Propulsion Laboratory, Pasadena, CA

2. A Simplified Method for Evaluating Wave Propagation in Complex Structures - J.D. COLTON and T.P. DESMOND, SRI International, Menlo Park, CA

3. High g Pyrotechnic Shock Simulation Using Metal-to-Metal Impact - M. BAI and W. THATCHER, Motorola, GED, Scottsdale, AZ

4. An Experimental Design for Total Container Impact Response Modeling at Extreme Temperatures - V.P. KOBLER, U.S. MIRADCOM, Huntsville, AL, R.M. WYSKIDA and J.D. JOHANNES, The University of Alabama in Huntsville, Huntsville, AL

BREAK

5. **Empirical Procedures for Estimating Recoilless Rifle Breech Blast Overpressures** - P.S. WESTINE and R.E. RICKER, Southwest Research Institute, San Antonio, TX

6. **Blast from Bursting, Frangible Pressure Spheres** - E.D. ESPARZA and W.E. BAKER, Southwest Research Institute, San Antonio, TX

7. **Test Evaluation of Shock Buffering Concept for Hydrodynamic Ram Induced by Yawing Projectile Impacting a Simulated Integral Fuel Tank** - P.H. ZABEL, Southwest Research Institute, San Antonio, TX

SUPPLEMENTARY

Air Blast Response of Tapered Beams Using Finite Element Method - A.V. SINGH, Defence Research Establishment, Suffield, Alberta, Canada

Prediction of Fragment Velocities and Trajectories - J.J. KULESZ, L.M. VARGAS, and P.K. MOSELEY, Southwest Research Institute, San Antonio, TX

Session 2A (Unclassified) 9:00 A.M. Wednesday, October 18
Adams Room

MODAL AND IMPEDANCE ANALYSIS

Chairman: Dr. Ben Wada, Jet Propulsion Laboratory, Pasadena, CA
Cochairman: Dr. George Morosow, Martin Marietta Corporation, Denver, CO

1. An Impedance Technique for Determining Low Frequency Payload Environments - K.R. PAYNE, Martin Marietta Corporation, Denver, CO

2. Modification of Flight Vehicle Vibration Modes to Account for Design Changes - C.W. COALE and M.R. WHITE, Lockheed Missiles & Space Company, Sunnyvale, CA

3. A Statistical Look at Modal Displacement Response to Segnential Excitation - W.J. KACENA, Martin Marietta Corporation, Denver, CO

BREAK

4. On Determining the Number of Dominant Modes in Sinusoidal Structural Response - W.L. HALLAUER, Jr. and A. FRANCK, Virginia Polytechnic Institute and State University, Blacksburg, VA

5. Lateral and Tilt Whirl Modes of Flexibly Mounted Flywheel Systems: Analysis and Experiment - C.W. BERT and T.L.C. CHEN, University of Oklahoma, Norman, OK

6. On Combining Modal Responses in the Shock Spectrum Method of Analysis - S.S. GASSEL and J.J. CULLENS, Westinghouse Electric Corporation, West Mifflin, PA

SUPPLEMENTARY

Development and Application of the Mobile Dynamic Analysis Laboratory (MODALAB) - R.C. STROUD, Lockheed Missiles and Space Company, Sunnyvale, CA, S. SMITH and G.A. HAMMA, Lockheed Missiles and Space Company, Palo Alto, CA

Session 2B (Unclassified) 9:00 A.M. Wednesday, October 18
Monroe Room

HUMAN RESPONSE TO VIBRATION AND SHOCK

Chairman: Dr. John C. Guignard, Naval Aerospace Medical Research Laboratory Detachment, New Orleans, LA
Cochairman: Mr. Donald Wasserman, National Institute for Occupational Safety and Health, Cincinnati, OH

1. Problems and Progress in Biodynamics - Dr. H.E. VON GIERKE, 6570th Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH

2. Musculoskeletal Response to Impact Loading - Dr. L. KAZARIAN, 6570th Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH

3. Human Impact Acceleration Facility - W.H. MUZZY III, Jr. and G.C. WILLEMS, Naval Aerospace Medical Research Laboratory Detachment, New Orleans, LA

BREAK

4. Whole-Body Vibration of Heavy Equipment Operators - D.E. WASSERMAN, National Institute for Occupational Safety & Health, Cincinnati, OH

5. Vibration Characteristics of the Hand - Dr. D.D. REYNOLDS, University of Pittsburgh, PA

6. Recent Reserach on Passenger Reaction to Vehicle Ride Quality - Dr. I.D. JACOBSON and A.R. KUHLTHAU, University of Virginia, Charlottesville, VA

7. Research Related to the Expansion and Improvement of Human Vibration Exposure Criteria - Dr. R.W. SHOENBERGER, 6570th Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH

Session 2C (Unclassified) 2:00 P.M. Wednesday, October 18
Adams Room

ISOLATION AND DAMPING

Chairman: Professor Frederick Nelson, Tufts University, Medford, MA
Cochairman: Dr. John Henderson, Air Force Materials Laboratory, Wright-Patterson AFB, OH

1. Computer Aided Design of Passive Vibration Isolators for Airborne Electro-Optical Systems - P.W. WHALEY, Air Force Institute of Technology, Wright-Patterson AFB, OH and J. PEARSON, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH

2. Transmissibility Across Completely Free Thin Square Plates with and without Structural Damping - B.M. PATEL, Lord Kinematics, Erie, PA

3. Liquid Spring Shock Isolator Modeling by System Identification - P.N. SONNENBURG, B.H. WENDLER, and W.E. FISHER, U.S. Army Corps of Engineers Construction Engineering Research Lab., Champaign, IL

BREAK

4. Preliminary Design of Practical Damping Applications - L. ROGERS, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH

5. Design of Turbine Blades for Effective Slip Damping at High Rotational Speeds - D.I.G. JONES, Air Force Materials Laboratory, Wright-Patterson AFB, OH, and A. MUSZYNSKA, Polish Academy of Sciences, Warsaw, Poland

6. A Generalized Derivative Model for an Elastomer Damper - R.L. BAGLEY and P.J. TORVIK, Air Force Institute of Technology, Wright-Patterson AFB, OH

7. Low Cost Measurement of Material Damping Behavior - D.I.G. JONES, Air Force Materials Laboratory, Wright-Patterson AFB, OH

Session 2D (Unclassified) 2:00 P.M. Wednesday, October 18
Monroe Room

DYNAMIC ANALYSIS

Chairman: Mr. Sumner A. Leadbetter, NASA, Langley Research Center, Hampton, VA
Cochairman: Mr. Jess Jones, NASA, Marshall Space Flight Center, Huntsville, AL

1. Reflection and Transmission of Fluid Transients at Elbows - J.W. PHILLIPS, University of Illinois at Urbana-Champaign, Urbana, IL

2. Stability Analysis and Response Characteristics of Two-Degree of Freedom Nonlinear Systems - M. SUBUDHI and J.R. CURRERI, Brookhaven National Laboratory, Upton, NY

3. Application of Random Time Domain Analysis to Flight Data - S.R. IBRAHIM, Old Dominion University, Norfolk, VA

BREAK

4. Shock Spectra Design Methods for Equipment-Structure Systems - J.L. SACKMAN and J.M. KELLY, University of California, Berkeley, CA

5. A Computational Model Describing the Initiation of Silver Acetylide-Silver Nitrate Explosive by an Intense Light Source - F.H. MATHEWS, Sandia Laboratories, Albuquerque, NM

6. Analysis of the Motion of a Barrel Tamped Explosively Propelled Plate - R.A. BENHAM, Sandia Laboratories, Albuquerque, NM

7. A Stability Theorem for a Dynamically Loaded Linear Viscoelastic Structure - D.W. NICHOLSON, Naval Surface Weapons Center, Silver Spring, MD

SUPPLEMENTARY

Analog Double Integration of Shock Pulses - K. PELEG and R. LUND, Michigan State University School of Packaging, East Lansing, MI

Session 3A (Unclassified) 9:00 A.M. Thursday, October 19
Adams Room

STRUCTURE-MEDIUM INTERACTION

Chairman: Dr. Robert O. Belsheim, NKF Engineering Associates, Inc., Silver Spring, MD
Cochairman: Dr. Jack Kalinowski, Naval Underwater Systems Center, New London, CT

1. Long Wave Length Effects in Fluid-Structure Interaction Calculations - R.E. NICKELL and R.S. DUNHAM, Pacifica Technology, Del Mar, CA

2. Late-Time Ground Motion Calculations for Stemming Material in an Underground Nuclear Test - D.F. PATCH, Pacifica Technology, Del Mar, CA

3. Simplified Shock Design of Underground Structures - A.K. GUPTA, IIT Research Institute, Chicago, IL

BREAK

4. Failure of Underground Concrete Structures Subjected to Blast Loadings - P.T. NASH, G.R. GRINER, USAF Armament Laboratory, Eglin AFB, FL and C.A. ROSS, University of Florida, Eglin AFB, FL

5. Theoretical Investigation of Loads on Buried Structures - R.R. ROBINSON, IIT Research Institute, Chicago, IL and M.A. PLAMONDON, S.A. CHANG, Air Force Weapons Laboratory, Albuquerque, NM

6. Optimization of Reinforced Concrete Slabs to Resist Blast Loading - J.M. FERRITTO, Civil Engineering Laboratory, Port Hueneme, CA

SUPPLEMENTARY

A Numerical Comparison with an Exact Solution for the Transient Response of a Cylinder Immersed in a Fluid - D.S. LUCAS and M.E. GILTRUD, Naval Surface Weapons Center, Silver Spring, MD

Session 3B (Unclassified) 9:00 A.M. Thursday, October 19
Monroe Room

CASE STUDIES IN DYNAMICS

Chairman:	Dr. Anthony Amos, NASA, Headquarters, Washington, D.C.
Cochairman:	Mr. Don McCutchen, NASA, Lyndon B. Johnson Space Center, Houston, TX

1. Foil System Fatigue Load Environments for Commercial Hydrofoil Operation - D.L. GRAVES, Boeing Marine Systems Co., Seattle, WA

2. Protection of a Large Superconducting MHD Magnet from Random Load-Induced Fatigue Failure - D. KRAJCINOVIC, University of Illinois at Chicago Circle, Chicago, IL, R.A. VALENTIN, W.P. LAWRENCE, Argonne National Laboratory, Argonne, IL and E.J. RIPLING, Materials Research Laboratories Inc., Glenwood, IL

3. Evaluation of Rotor-Bearing System Dynamic Response to Unbalance - R.E. THALLER and D.W. OZIMEK, Aeronautical Systems Division, Wright-Patterson AFB, OH

4. Experimental Investigation of Dynamic Characteristics of Turbine Generator and Its Low Tuned Foundation - S.P. YING and M.E. FORMAN, Gilbert/Commonwealth, Jackson, MI, R.R. DRUMM, Pennsylvania Power and Light Company, Allentown, PA

BREAK

5. Selected Topics from the Structural Acoustics Program for the B-1 Aircraft - P.M. BELCHER, Rockwell International Corp., Los Angeles, CA

6. Combined Vibration/Temperature/Sideload Environmental Testing of UHF Blade Antennas - R.E. VOLKER, McDonnell Aircraft Company, St. Louis, MO

7. An Investigation of Operator Ride Quality in Tractor-Trailer Trucks - T.G. CARNE and L.T. WILSON, Sandia Laboratories, Albuquerque, NM

SUPPLEMENTARY

An Assessment of the Machinery Noise Problem of the Fabricated Metal Products Industry - E.P. BERGMAN, Southwest Reserach Institute, San Antonio, TX

Session 3C (Unclassified) 9:00 A.M. Thursday, October 19
Adams Room

SHORT DISCUSSION TOPICS

Chairman:	Mr. Roland Seely, Naval Weapons Handling Evaluation Facility, Earle, NJ
Cochairman:	Charles Fridinger, Naval Surface Weapons Center, Silver Spring, MD

This session will program papers covering progress reports on current research efforts and unique ideas, hints and kinks on instrumentation, fixtures, testing, analytical short cuts and so forth. It is intended to provide a means for up-to-the-minute coverage of research programs and a forum for the disucssion of useful ideas and techniques considered too short for a full-blown paper. Complete titles of short talks will be published in the final program.

Session 3D (Classified) 2:00 P.M. Thursday, October 19
Goddard Space Flight Center

CLASSIFIED SESSION

Chairman:	Mr. Anthony Paladino, Naval Sea Systems Command, Washington, D.C.
Cochairman:	Mr. Kenneth Cornelius, Naval Ship R&D Center, Bethesda, MD

1. EMP Hardening of Ships from a Shock and Vibration Point of View- R.J. HAISLMAIER, Naval Surface Weapons Center, Silver Spring, MD

2. The Analysis of Response to Acoustic Excitation of Ramjet Combustors Lined with Thermally Insulating Materials - T.B. JONES, Jr., The Marquardt Company, Van Nuys, CA

3. Initial Considerations of Near Miss Ship Shock - R.G. MERRITT, R.L. WOODFIN, and W.N. JONES, Naval Weapons Center, China Lake, CA

BREAK

4. Instrument Panel Vibration Reduction of U.S.S. Glover - E.V. THOMAS, David W. Taylor Naval Ship Research and Development Center, Annapolis, MD

5. Shock Isolation Platform for Sea Sparrow Launcher - P.V. ROBERTS, Raytheon Corp., Bedford, MA

6. The Residual Hydrostatic Strength of Initially Shock Damage Pressure Hulls - M.E. GILTRUD, Naval Surface Weapons Center, Silver Spring, MD

SHORT COURSES

OCTOBER

CURRENT DEVELOPMENTS IN UNDERWATER ACOUSTICS

Dates: October 2-6, 1978

Place: University Park, Pennsylvania

Objective: This course will cover linear and nonlinear propagation of sound in the ocean, transducers, and sources of underwater noise.

Contact: Robert E. Beam, The Pennsylvania State University, Keller Conference Center, University Park, PA 16802 - (814) 865-5141.

SONAR AND SEISMIC SIGNAL PROCESSING

Dates: October 9-12, 1978

Place: University Park, Pennsylvania

Objective: This course is designed to provide those scientists and engineers practicing in the fields of underwater acoustics or seismic exploration an understanding of the principles and techniques used for the detection of underwater and underground signals.

Contact: Robert E. Beam, The Pennsylvania State University, Keller Conference Center, University Park, PA 16802 - (814) 865-5141.

MACHINE PROTECTION AND MALFUNCTION DIAGNOSIS

Dates: October 9-13, and December 11-15, 1978

Place: Carson City, Nevada

Objective: Topics to be covered include: Measuring and monitoring parameters for predictive maintenance; Eddy current probe and proximitor theory of operation; Installation procedures and common pitfalls; Permanent machine monitoring systems; System calibration procedures; Thrust position measurements; Troubleshooting the system; Transducer polarity rules; Hazardous area considerations; Introduction to machine data acquisition; Oscilloscope theory and operation; Oscilloscope cameras; Tunable filters, Vector filter-phase meter; Tape recorders; Keyphasor theory; and Electrical runout.

Contact: Training Manager, Bently Nevada Corporation, P.O. Box 157, Minden, Nevada 89423 - (702) 782-3611.

VIBRATION DAMPING

Dates: October 23-26, 1978

Place: University of Dayton Research Institute

Objective: To cover the science and art of utilizing vibration damping materials to reduce the undesirable effects of noise and vibration on structures and equipment. The course is designed to teach the background, basic analytical methods and experimental techniques needed for design and application of damping treatments in aircraft and spacecraft structures, engines and equipment. Step by step procedures will be discussed, along with case histories. The fee for early registration is $410 (before October 2, 1978) and $425 thereafter.

Contact: Vibration Damping Short Course, Research Institute - KL 501, University of Dayton, Dayton, OH 45469, Attn: Dale H. Whitford, (513) 229-4235.

MACHINERY VIBRATION SEMINAR

Dates: October 24-26, 1978

Place: MTI, Latham, New York

Objective: To cover the basic aspects of rotor-bearing system dynamics. The course will provide a fundamental understanding of rotating machinery vibrations; an awareness of available tools and techniques for the analysis and diagnosis of rotor vibration problems; and an appreciation of how these techniques are applied to correct vibration problems. Technical personnel who will benefit most from this course are those concerned with the rotor dynamics evaluation of motors, pumps, turbines, compressors, gearing, shafting, couplings, and similar mechanical equipment. The attendee should possess an engineering degree with some understanding of mechanics of materials and vibration theory. Appropriate job functions include machinery designers; and plant, manufacturing, or service engineers.

Contact: Mr. P.E. Babson, Mktg. Mgr., Machinery Diagnostics, MTI, 968 Albany-Shaker Rd., Latham, NY 12110 - (518) 785-2371.

STRUCTURAL ANALYSIS SHORT COURSE

The following short courses in structural analysis are being offered by Schaeffer Analysis in October of 1978 in Boston, Massachusetts.

NASTRAN related courses

- DMAP and Substructural Analysis Using NASTRAN
  October 16-19, 1978

Composite Materials

- Structural Applications of Composite Materials
  October 23-26, 1978

Contact: Schaeffer Analysis, Kendall Hill Rd., Mont Vernon, New Hampshire 03057 - (603) 673-3070.

NOVEMBER

DIGITAL SIGNAL PROCESSING

Dates: November 6-10, 1978
Place: The George Washington University
Washington, D.C.
Objective: The course is designed for engineers, scientists, technical managers, and others who desire a better understanding of the theory and applications of digital signal processing. The objective of this course is to provide the participants with the essentials of the design of IIR and FIR digital filters, signal detection and estimation techniques, and the development of Fast Fourier Transform Algorithms. The applications of digital signal processing to speech processing will also be discussed. The mathematical concepts needed for understanding this course will be developed during the presentation.

Contact: Continuing Engineering Education Program, George Washington University, Washington, D.C. 20052 - (202) 676-6106 or toll free (800) 424-9773.

VIBRATION AND SHOCK TESTING

Dates: November 6-10, 1978
Place: Washington, D.C.
Objective: Lectures are combined with physical demonstrations: how structures behave when mechanically excited, how input and response forces and motions are sensed by pickups, how these electrical signals are read out and evaluated, also how measurement systems are calibrated. The relative merits of various types of shakers and shock machines are considered. Controls for sinusoidal and random vibration tests are discussed.

Contact: Wayne Tustin, Tustin Institute of Tech., Inc., 22 East Los Olivos St., Santa Barbara, CA 93105 - (805) 963-1124.

16TH ANNUAL RELIABILITY ENGINEERING AND MANAGEMENT INSTITUTE

Dates: November 6-10, 1978
Place: Tuscon, Arizona
Objective: The course will cover the following topics: Reliability engineering theory and practice; Mechanical reliability prediction; Reliability testing and demonstration; Maintainability engineering, Product liability; and Reliability and Maintainability Management.

Contact: Dr. Dimitri Kececioglu, Aerospace and Mechanical Engineering Dept., University of Arizona, Bldg. 16, Tucson, AZ 85721 - (602) 626-2495/626-3901/626-3054.

JANUARY

STRUCTURED PROGRAMMING AND SOFTWARE ENGINEERING

Dates: January 8-12, 1979
Place: The George Washington University
Objective: This course provides up-to-date technical knowledge of logical expression, analysis, and invention for performing and managing software architecture, design, and production. Presentations will cover principles and applications in structured programming and software engineering, including stepwise refinement, program correctness, and top-down system development.

Contact: Continuing Engineering Education Program, George Washington University, Washington, D.C. 20052 - (202) 676-6106 or toll free (800) 424-9773.

MARCH

MEASUREMENT SYSTEMS ENGINEERING

Dates: March 12-16, 1979

Place: Phoenix, Arizona

MEASUREMENT SYSTEMS DYNAMICS

Dates: March 19-23, 1979

Place: Phoenix, Arizona

Objective: Program emphasis is on how to increase productivity, cost-effectiveness and data-validity of data acquisition groups in the field and in the laboratory. The program is intended for engineers, scientists, and managers in industrial, governmental, and educational organizations. Electrical measurements of mechanical and thermal quantities are the major topics.

Contact: Peter K. Stein, 5602 E. Monte Rosa, Phoenix, AZ 85018 - (602) 945-4603/946-7333.

NEWS BRIEFS

news on current and Future Shock and Vibration activities and events

CALL FOR PAPERS
Transducers and Their Applications

The 10th Transducer Workshop will be held 12-14 June 1979, at the U.S. Air Force Academy, Colorado Springs, Colorado. The Workshop will cover the measurement of physical parameters with Transducer Technology. Applications are in flight, field and laboratory testing. Paper presentations should be only 10 to 15 minutes long. The Workshop is sponsored by the Transducer Committee of the Telemetry Group, which reports to the Range Commanders Council. Papers may be about transducers, their conditioners, or entire transducer-based systems. Measurands include force, pressure, acceleration, velocity, displacement, temperature and others. Topics include the calibration and evaluation of transducers and their conditioners, in addition to their use in engineering tests and measurements.

Abstracts of about 200 words are requested and should be sent by September 20, 1978 to: National Bureau of Standards, Attn: Paul S. Lederer, Div. 722, Washington, D.C. 20234 - (301)921-3821.

SYMPOSIUM ON FUTURE TRENDS IN COMPUTERIZED STRUCTURAL ANALYSIS AND SYNTHESIS

This Symposium will be held October 30 - November 1, 1978 at the Marriott Hotel, Washington, D.C. It will be co-sponsored by George Washington University and NASA - Langley Research Center in cooperation with the National Science Foundation and the American Society of Civil Engineers. Topics to be discussed in this symposium include structural analysis and design of systems, supercomputers and microprocessors, advances and trends in numerical analysis, symbolic computing and minicomputer applications, structural synthesis, advances and trends in engineering software development, material characterization and structural modeling, nonlinear analysis, interactive computer graphics, computer aided instruction and engineering software systems, structural modeling and advanced structural applications. Sessions on research in progress on computers and structural analysis and synthesis will be held.

Make checks payable to: The George Washington University and mail before October 2, 1978, to: Professor Ahmed K. Noor, Mail Stop 246, The George Washington University, NASA - Langley Research Center, Hampton, Virginia 23665.

INTER-NOISE 78 PROCEEDINGS PUBLISHED

"Designing for Noise Control," the Proceedings of the 1978 International Conference on Noise Control Engineering contains the papers presented at INTER-NOISE 78 which was held in San Francisco, California, on 8-10 May 1978. INTER-NOISE 78 was sponsored by the International Institute of Noise Control Engineering and organized by INCE/U.S.A. The book of Proceedings, edited by Conference Chairman William W. Lang, contains papers covering all branches of noise control engineering, including machinery noise control, industrial noise control, in-plant noise control, transportation noise control, instrumentation and analysis techniques for noise control, and building noise control. Copies of the INTER-NOISE 78 Proceedings are available from INTER-NOISE 78, P.O. Box 3469, Arlington Branch, Poughkeepsie, NY 12603. The postpaid price is \$35.00. Overseas orders must include \$7.00 extra if shipment is to be by air.

PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON FRACTURE MECHANICS

Proceedings of the International Symposium on Fracture Mechanics held at the George Washington University, September 11-13, 1978, will be available through the University Press of Virginia. This symposium, sponsored by the Office of Naval Research, presents an overview of the fracture problems in ship and aircraft structures, as well as an international review of the state-of-the-art in many areas of fracture mechanics research. Included are results of both theoretical and experimental studies of fracture and fatigue in a variety of materials and structures. Various aspects of fracture are discussed for composites, polymers, ceramics and metallic materials under wide ranges of loading and environment. Fracture mechanics technology is reviewed through fracture case studies, discussions of recent advances in nondestructive flaw detection, and applications to nuclear reactors, gas turbines, and rocket motors. This book, edited by Drs. N. Perrone, H. Liebowitz, and D. Mulville, will be available in September. It can be ordered form the University Press of Virginia, Box 3608, University Station, Charlottesville, VA 22903, for $25.00.

NOISE-CON 79
April 30 to May 2, 1979, Purdue University

The conference will be sponsored by Purdue University and the Institute of Noise Control Engineering/USA. The theme of the 1979 National Conference on Noise Control Engineering in machinery noise control. Several different sessions will be held in which papers will be presented on noise from industrial machinery, engines, pumps, compressors, and home appliances. Each session in the Conference will consist of invited and a limited number of contributed papers. Contributed papers will be selected by review of long abstracts (maximum 1000 words and up to one figure and 5 equations if needed). The deadline for receipt of these abstracts is December 15, 1978. Prior to NOISE-CON 79, there will be a special seminar on machinery noise control, on April 26-28, 1979. For further information on the conference or seminar, please write: NOISE-CON 79, 116 Stewart Center, Purdue University, West Lafayette, IN 47907 - (317)749-2533. Abstracts should be mailed to: Professor J.W. Sullivan, Program Chairman, Ray W. Herrick Labs., Purdue University, West Lafayette, IN 47907 - (317)749-6345.

CALL FOR PAPERS
Design and Applications: Advanced Composite Materials

The Mechanical Failure Prevention Group (MFPG) sponsored by the National Bureau of Standards; Office of Naval Research, Department of the Navy; Department of Energy; and NASA Goddard Space Flight Center will hold its 29th Symposium at the National Bureau of Standards, Gaithersburg, Maryland on May 22-24, 1979. Papers are desired in the following areas: Applications in land, marine, and aerospace systems; Analytical techniques; Fabrication techniques; Non-destructive testing; Failure modes; Environmental effects; and Materials. Proceedings in the form of extended abstracts, 2-4 typewritten pages, will be published by the National Bureau of Standards. Closing date for initial abstracts is January 1, 1979 and for extended abstracts, April 30, 1979. Abstracts should be sent to Jesse E. Stern, Code 721, Goddard Space Flight Center, Greenbelt, Maryland 20771 - (301)982-2657.

NOISE CONTROL ENGINEERING BEGINS 6TH YEAR OF PUBLICATION

NOISE CONTROL ENGINEERING, the technical journal of the Institute of Noise Control Engineering (INCE) has, with Volume 11, entered its sixth year of publication. The bimonthly journal, edited by Professor Malcolm J. Crocker of Purdue University, is the only magazine publisned in the United States which prints refereed articles concerned exclusively with noise control.

NOISE CONTROL ENGINEERING is available for $30.00 per year. Students are eligible for a one-time, three-year subscription for $30.00. Individual subscribers become Associates of the Institute of Noise Control Engineering and also receive the bimonthly publication NOISE/NEWS. For further information, contact NOISE CONTROL ENGINEERING, P.O. Box 3206, Arlington Branch, Poughkeepsie, New York 12603.

SESA TO HOLD 1978 MEETING IN INDIANAPOLIS

The Society for Experimental Stress Analysis, an international engineering society will hold its 1978 Fall Meeting at the Sheraton West Hotel, Indianapolis, IN on October 23-25.

Members of the Central Indiana Section of the SESA are sponsoring the meeting. The program offers four technical seminars, seven workshop courses, a full schedule of SESA technical and administrative committee meetings and several outings and social events.

The technical seminars on October 23 are being organized by the Structural Testing Committee, the Residual Stress Committee and the Fracture Committee of the SESA. Two sessions are entitled "A Potpourri of Structural Testing", a third is "Residual-stress Measurement", and the fourth is "Determination of Stress Intensities and Related Quantities". The seminar program features twenty invited papers.

Seven workshops are offered on October 24 and 25: a two-day structural-dynamics workshop and six one-day workshops on transducers, strain gages and brittle coatings, fracture mechanics, plastic modeling, strain gages in hostile environments and data transmission.

In addition to the technical and workshop programs, twenty SESA technical and administrative committees will hold working meetings during the three days.

For additional information, please contact: Jane Austin, Editorial Assistant, SESA, 21 Bridge Square, P.O. Box 277, Saugatuck Station, Westport, CT 06880 - (203) 227-0829.

ABSTRACT CATEGORIES

ANALYSIS AND DESIGN

- Analogs and Analog Computation
- Analytical Methods
- Dynamic Programming
- Impedance Methods
- Integral Transforms
- Nonlinear Analysis
- Numerical Analysis
- Optimization Techniques
- Perturbation Methods
- Stability Analysis
- Statistical Methods
- Variational Methods
- Finite Element Modeling
- Modeling
- Digital Simulation
- Parameter Identification
- Design Information
- Design Techniques
- Criteria, Standards, and Specifications
- Surveys and Bibliographies
- Tutorial
- Modal Analysis and Synthesis

COMPUTER PROGRAMS

- General
- Natural Frequency
- Random Response
- Stability
- Steady State Response
- Transient Response

ENVIRONMENTS

- Acoustic
- Periodic
- Random
- Seismic
- Shock
- General Weapon
- Transportation

PHENOMENOLOGY

- Composite
- Damping
- Elastic
- Fatigue
- Fluid
- Inelastic
- Soil
- Thermoelastic
- Viscoelastic

EXPERIMENTATION

- Balancing
- Data Reduction
- Diagnostics
- Equipment
- Experiment Design
- Facilities
- Instrumentation
- Procedures
- Scaling and Modeling
- Simulators
- Specifications
- Techniques
- Holography

COMPONENTS

- Absorbers
- Shafts
- Beams, Strings, Rods, Bars
- Bearings
- Blades
- Columns
- Controls
- Cylinders
- Ducts
- Frames, Arches
- Gears
- Isolators
- Linkages
- Mechanical
- Membranes, Films, and Webs
- Panels
- Pipes and Tubes
- Plates and Shells
- Rings
- Springs
- Structural
- Tires

SYSTEMS

- Absorber
- Acoustic Isolation
- Noise Reduction
- Active Isolation
- Aircraft
- Artillery
- Bioengineering
- Bridges
- Building
- Cabinets
- Construction
- Electrical
- Foundations and Earth
- Helicopters
- Human
- Isolation
- Material Handling
- Mechanical
- Metal Working and Forming
- Off-Road Vehicles
- Optical
- Package
- Pressure Vessels
- Pumps, Turbines, Fans, Compressors
- Rail
- Reactors
- Reciprocating Machine
- Road
- Rotors
- Satellite
- Self-Excited
- Ship
- Spacecraft
- Structural
- Transmissions
- Turbomachinery
- Useful Application

ABSTRACTS FROM THE CURRENT LITERATURE

Copies of articles abstracted in the DIGEST are not available from the SVIC or the Vibration Institute (except those generated by either organization). Inquiries should be directed to library resources. Government reports can be obtained from the National Technical Information Service, Springfield, VA 22151, by citing the AD-, PB-, or N- number. Doctoral dissertations are available from University Microfilms (UM), 313 N. Fir St., Ann Arbor, MI; U.S. Patents from the Commissioner of Patents, Washington, D.C. 20231. Addresses following the authors' names in the citation refer only to the first author. The list of periodicals scanned by this journal is printed in issues 1, 6, and 12.

ABSTRACT CONTENTS

ANALYSIS AND DESIGN

ANALYTICAL METHODS

(Also see No. 1288)

78-1209

A Direct Method for Analyzing the Forced Vibrations of Continuous Systems Having Damping

A.W. Leissa
Dept. of Engrg. Mechanics, Ohio State Univ., Columbus, OH 43210, J. Sound Vib., 56 (3), pp 313-324 (Feb 8, 1978) 3 tables, 16 refs

Key Words: Forced vibrations, Damped structures

The purpose of this paper is to extend the Rayleigh-Ritz-Galerkin methods to problems of forced vibrations of continuous bodies having damping. In particular it is intended to show how the method may be used without knowing eigenfunctions of free vibration and without having access to large scale digital computers.

78-1210

Forced Vibrations of Systems with Retardation and Damping

G.N. Bojadziev
Dept. of Mathematics, Simon Fraser Univ., Burnaby, British Columbia V5A 1S6, Canada, J. Sound Vib., 57 (1), pp 79-88 (Mar 8, 1978) 2 figs, 11 refs

Key Words: Forced vibration, Damping effects

The non-linear oscillatory processes of physical systems under the influence of an external force, and containing retardation and damping effects, are considered. An application is made to a generalized Van der Pol equation.

78-1211

First Passage Time for Oscillators with Non-Linear Restoring Forces

J.B. Roberts
School of Engrg. and Appl. Sciences, Univ. of Sussex, Brighton BN1 9QT, UK, J. Sound Vib., 56 (1), pp 71-86 (Jan 8, 1978) 9 figs, 15 refs

Key Words: Failure analysis, Probability theory

The Markov property of the energy envelope of a randomly excited, lightly damped oscillator, with a non-linear restoring force, is used as the basis of a numerical method for calculating the probability of first passage failure, P(T), in an interval 0–T.

78-1212

Forced Vibration of Special Classes of Nonlinear and Hysteretic Oscillators

S.J. Stott
Ph.D. Thesis, Univ. of Southern California (1978) Avail: Micrographics Dept., Doheny Library, USC, Los Angeles, CA 90007

Key Words: Oscillators, Forced vibration

This dissertation is an analytical investigation of the dynamic response of three special classes of nonlinear oscillators. In the first problem class studied, two solutions are presented for determining the displacement response of a harmonically excited, single-degree-of-freedom (SDOF) hysteretic oscillator. In the second problem class studied, a vibration neutralizer with motion-limiting stops is analyzed by two proposed solutions to determine its displacement response to stationary random excitation. Finally, in the third problem class studied, two analytic solutions are presented for the determination of the displacement response of an SDOF damped bilinear hysteretic oscillator subjected to stationary random excitation.

INTEGRAL TRANSFORMS

78-1213

Application of Laplace Transform Technique to the Solution of Certain Third-Order Non-Linear Systems

S.G. Joshi and P. Srinivasan
Dept. of Mech. Engrg., Indian Inst. of Science, Bangalore 560012, India, J. Sound Vib., 57 (1), pp 41-50 (Mar 8, 1978) 6 figs, 1 table, 8 refs

Key Words: Laplace transformation, Random excitation, Nonlinear systems

A number of papers have appeared on the application of operational methods and in particular the Laplace transform to problems concerning non-linear systems of one kind or other. This, however, has met with only partial success in solving a class of non-linear problems as each approach has some limitations and drawbacks. In this study the approach of Baycura has been extended to certain third-order non-

linear systems subjected to non-periodic excitations, as this approximate method combines the advantages of engineering accuracy with ease of application to such problems. Under non-periodic excitations the method provides a procedure for estimating the maximum response amplitude, which is important from the point of view of a designer. Limitations of such a procedure are brought out and the method is illustrated by an example taken from a physical situation.

78-1214

Fundamentals of the Discrete Fourier Transform

M.H. Richardson

Hewlett Packard Co., Santa Clara, CA., S/V, Sound Vib., 12 (3), pp 40-46 (Mar 1978) 10 figs, 1 table

Key Words: Fourier transformation, Discrete Fourier transform

The important concepts which must be understood in order to avoid significant errors in the application of the Discrete Fourier Transform (DFT) to measured data are presented. The authors begin by examining the Fourier transform and some of its properties, and then show how a fundamental concept called "windowing" can be applied to the Fourier transform to derive the DFT and all of its properties. Using the convolution property, or as it is called here, the windowing rule or Fourier transforms, they define the concepts of sampling, aliasing, leakage and the wrap-around error.

OPTIMIZATION TECHNIQUES

(Also see Nos. 1220, 1287)

78-1215

A Structural Optimization Method Combining Finite Element and Control Theory Techniques

C.S. De Barcellos

Ph.D. Thesis, Univ. of Minnesota, 155 pp (1977) UM 7802633

Key Words: Minimum weight design, Optimization, Finite element technique, Rods, Beams, Columns

A formulation based on control theory and finite element analysis is suggested for obtaining optimality conditions for minimum-mass design of practical structures. The necessary conditions for optimality are derived using the concepts of physical and mathematical finite elements.

STATISTICAL METHODS

78-1216

A Unified Expression for the Multivariate Joint Probability Density Function of the Output Fluctuation of an Arbitrary Linear Vibratory System with Arbitrary Random Excitation

M. Ohta, S. Yamaguchi, and S. Hiromitsu

Dept. of Electrical Engrg., Hiroshima Univ., Hiroshima, Japan, J. Sound Vib., 56 (2), pp 229-241 (Jan 22, 1978) 4 figs, 10 refs

Key Words: Probability theory, Spectral energy distribution, Vibrating structures, Random excitation

It is well-known that full information on the statistical properties of state variables can be derived by finding the multivariate joint probability density function. A new theoretical expression for the multivariate joint probability density function of an output response is derived exactly in the case when a general random signal having an arbitrary probability distribution and correlation properties is passed through an arbitrary linear vibratory system of finite order. The result is given as an explicit solution, in a general series expansion form, with functional dependence on the input statistics and vibratory system parameters.

78-1217

Risk Analysis of Structures in Earthquake Engineering

D. Hsu

Ph.D. Thesis, Purdue Univ., 272 pp (1977) UM 7803236

Key Words: Earthquake damage, Monte Carlo method

The methodology presented can be used to relate the damage of individual structures to earthquakes with various intensities. The damage of the structure is defined and classified from the viewpoint of structural mechanics. The earthquake information with different intensities is collected from a two-hundred-year period of strong earthquake records. Monte Carlo technique is applied to estimate the probability of damage state for individual structures for earthquakes with different intensities. Damage boundaries for a portal frame have been derived in detail.

FINITE ELEMENT MODELING

(Also see Nos. 1321, 1353, 1363)

78-1218

A Finite Element Analysis of the Impedance Properties of Irregular Shaped Cavities with Absorptive Boundaries

P.D. Joppa and I.M. Fyfe
Noise Tech. Staff, Boeing Commercial Airplane Co., Seattle, WA 98124, J. Sound Vib., 56 (1), pp 61-69 (Jan 8, 1978) 3 figs, 3 tables, 10 refs

Key Words: Finite element technique, Sound waves, Elastic wave, Acoustic impedance, Cavity-containing media

The impedance tube configuration is used to examine the application of the finite element method to a variety of acoustics problems with arbitrary boundary shapes and impedances. The governing equations and boundary conditions are established in a variational format to include permeable membranes and boundary forcing functions as required. A simple triangular element is used in the finite element model to obtain solutions which give good agreement with exact solutions, thus helping to establish the flexibility of the finite element method is acoustic applications.

MODELING

78-1219
Methods for the Experimental Model Finding in the Machine Dynamics (Verfahren zur experimentellen Modellfindung in der Maschinendynamik)
F. Holzweissig and H.J. Hardtke
TU Dresden, Sektion Grundlagen des Maschinenwesens, Bereich Dynamik und Betriebsfestigkeit, Maschinenbautechnik, 26 (11), pp 500-504 (Nov 1977) 9 figs, 9 refs
(In German)

Key Words: Mathematical models, Parameter identification technique, System identification technique

Methods, based on systems theory, for the determination of parameters in machine dynamics, are described. Using these methods the characteristic system functions are determined from the measurement of the input and output of the dynamic system for a random excitation function. The parameters of the system are derived from these characteristic system functions. Computer programs for the application of partial results are listed and the new developments are outlined.

PARAMETER IDENTIFICATION

78-1220
Influence of Stochastic Disturbances at the Identification of Linear Time Invariant Oscillation Systems (Einfluss zufälliger Störungen bei der Identifikation linearer zeitinvarianter Schwingungssysteme)
B. Heimann
Akademie der Wissenschaften der DDR, Zentralinstitut f. Mathematik und Mechanik, Maschinenbautechnik, 26 (11), pp 518-520 (Nov 1977) 3 figs
(In German)

Key Words: System identification technique, Error analysis, Optimization

In the systems identification method the excitation and systems response are measured experimentally with measurement errors. A procedure for optimizing these errors is described, with minimum square deviation as its optimum condition.

DESIGN TECHNIQUES

(Also see No. 1222)

78-1221
Earthquake Resistant Masonry Construction: National Workshop
R.A. Crist and L.E. Cattaneo
Center for Building Tech., National Bureau of Standards, Washington, D.C., Rept. No. NBS-BSS-106, 374 pp (Sept 1977)
PB-276 501/4GA

Key Words: Seismic design, Earthquake resistant structures, Masonry

The National Workshop on Earthquake Resistant Masonry Construction provided an exchange of information between researchers and practicing engineers for the purpose of orienting pertinent research toward national needs concerning current problems related to design criteria. These proceedings contain the reports presented by researchers and by users of design criteria, as well as transcripts of the discussions which followed the individual presentations. In addition, the proceedings include recommendations which emanated from working sessions held by five working groups of participants. Technical areas covered by the groups were code requirements, design criteria, mathematical models, test standardization and material properties, and retrofit and repair. The recommendations were derived to identify research which would lead to improved output in each of the technical areas in order to benefit national needs.

CRITERIA, STANDARDS, AND SPECIFICATIONS

(Also see No. 1221)

78-1222

Earthquake Design Criteria for Structures

G.W. Housner and P.C. Jennings

Earthquake Engrg. Res. Lab., California Inst. of Tech., Pasadena, CA., Rept. No. EERL-77-06, 65 pp (Nov 1977)

PB-276 502/2GA

Key Words: Standards and codes, Seismic design, Earthquake resistant structures

Seismic design criteria should provide clearly stated guidelines for engineering designers which will give equal earthquake resistance to all parts of a structure and will give the desired overall resistance to the structure itself. To achieve this, the seismic design criteria must restate a complex problem, that has unknowns and uncertainties, into an unambiguous, simplified form that takes into account the uncertainties of seismic hazards, material properties and structural behavior. The criteria should be formulated by the project engineer, taking into account all the degrees of conservatism introduced in the sequence of design steps.

78-1223

A Dilemma: Noise Abatement at General Aviation Airports

A.S. Harris

Bolt Beranek and Newman, Inc., 50 Moulton St., Cambridge, MA 02138, Noise Control Engr., 10 (2), pp 80-84 (Mar/Apr 1978) 1 fig, 2 tables, 8 refs

Key Words: Aircraft noise, Noise reduction, Standards and codes

The author discusses a two-phase study of aviation noise. In Phase I the noise problem was described by compiling a data base from which specific regulatory steps could be drawn. During Phase II an investigation was made of the various operational problems, airport restrictions, and regulatory actions that would be necessary to implement the noise abatement goal.

SURVEYS AND BIBLIOGRAPHIES

78-1224

Computer Programs for the Directional Response of Highway Vehicles

J.E. Bernard

Dept. of Mech. Engrg., Michigan State Univ., East Lansing, MI, Shock Vib. Dig., 10 (5), pp 3-8 (May 1978) 1 fig, 33 refs

Key Words: Reviews, Computer programs, Ride dynamics, Mathematical models, Tires, Brakes (motion arrestors), Suspension systems (vehicles)

This review delineates the state of the art in the simulation of the directional response of highway vehicles. Modeling of tires, brakes, and suspensions is stressed. Two peripheral matters – path-following techniques and the choice of computer hardware -- are also considered.

78-1225

On Seismic Waves. Part 1: Introduction

S. De

Old Engrg. Office, (Qrs.). Santiniketan, Birbhum, West Bengal, India, Shock Vib. Dig., 10 (5), pp 11-16 (May 1978) 5 figs, 1 table, 8 refs

Key Words: Reviews, Seismic waves

This review outlines the mathematical methods used to study seismic waves and theroetical developments associated with body waves, surface waves, and free oscillations of the earth. It is published in four parts: introduction; surface and guided waves; and mathematical methods.

78-1226

Parametric Vibration. Part V: Stochastic Problems

R.A. Ibrahim and J.W. Roberts

Arab Organization for Industrialization, Sakr Factory for Developed Industries, P.O. Box 33, Heliopolis, Cairo, Egypt, Shock Vib. Dig., 10 (5), pp 17-38 (May 1978) 5 figs, 33 refs

Key Words: Reviews, Parametric vibration, Stochastic processes

This final article of the series is a review of published work on the stability and response of linear and nonlinear vibratory systems under random parametric excitation. It is concerned principally with work that is directly relevant to actual problems in engineering dynamics and structural vibration. The three methods most widely used to analyze random vibration problems are: the Fokker-Planck method, the averaging method, and the Liapunov direct method. The results obtained with these approaches are reviewed, and additional methods that have been applied to specific problems are considered. Published experimental work and analog computer studies are described.

78-1227

Bibliography of Earthquake Engineering

K. Kanai

Dept. of Civil Engrg., Columbia Univ., New York, NY, Rept. No. NSF/RA-770304, NSF/ENV-73-07756-2, 500 pp (Aug 1977)
PB-276 249-T/GA

Key Words: Bibliographies, Earthquake resistant structures, Earthquake damage, Interaction: soil-structure

This bibliography of earthquake engineering literature is comprised of published articles up to the year 1971. Main topic areas include: earthquakes; ground vibrations; ground; structures; earthquake damage; earthquake resistant structures and earthquake resistant design; and foreign countries (seismic intensity, seismicity, earthquake damage, earthquake resistance regulations). The list consists of the reference number, author's name, title of the paper, and name, volume, year, and page of the source in which the paper was published.

MODAL ANALYSIS AND SYNTHESIS

78-1228
Response of Periodic Structures by Modal Analysis
R.C. Engels and L. Meirovitch
Dept. of Engrg. Science and Mech., Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061, J. Sound Vib., 56 (4), pp 481-493 (Feb 22, 1978) 9 figs, 9 refs

Key Words: Modal analysis, Periodic structures

A periodic structure is a structure consisting of identical substructures, coupled together in identical ways to form the complete system. The undamped response of such a system is derived by using a modal analysis technique. The procedure allows for arbitrary loads and takes full advantage of the periodic properties of the structure. The algorithm is based on a technique previously developed by the authors.

COMPUTER PROGRAMS

GENERAL
(Also see No. 1224)

78-1229
Method of Fan Sound Mode Structure Determination Computer Program User's Manual: Modal Calculation Program
G.F. Pickett, R.A. Wells, and R.A. Love
Commercial Products Div., Pratt and Whitney Aircraft Group, East Hartford, CT, Rept. No. NASA-CR-135295; PWA-5554-5, 74 pp (Aug 1977)
N78-17066

Key Words: Fans, Modal analysis, Computer programs

A computer user's manual describing the operation and the essential features of the Modal Calculation Program is presented. The modal Calculation Program calculates the amplitude and phase of modal structures by means of acoustic pressure measurements obtained from microphones placed at selected locations wthin the fan inlet duct. In addition, the Modal Calculation Program also calculates the first-order errors in the modal coefficients that are due to tolerances in microphone location coordinates and inaccuracies in the acoustic pressure measurements.

ENVIRONMENTS

ACOUSTIC
(Also see Nos. 1218, 1223, 1254, 1276, 1279, 1300, 1306)

78-1230
On the Resolvent of the Pekeris Operator with a Neumann Condition
D. Habault and P.J.T. Filippi
Laboratoire de Mecanique et d'Acoustique, Centre National de la Recherche Scientifique, 13274 Marseille Cedex 2, France, J. Sound Vib., 56 (1), pp 87-95 (Jan 8, 1978) 3 refs

Key Words: Sound waves, Harmonic waves, Elastic waves, Wave propagation

A constant thickness plane layer of homogeneous isotropic medium is limited, on one side, by a perfectly rigid plane, and, on the other side, by a second homogeneous isotropic medium occupying the half-space. The sound pressure due to a harmonic point spherical source is studied. An exact representation of the solution is given for both positions of the source: outside of or within the layer.

78-1231

Reflexion of a Spherical Wave by the Plane Interface Between a Perfect Fluid and a Porous Medium

P.J.T. Filippi and D. Habault
Laboratoire de Mecanique et d'Acoustique, Centre National de la Recherche Scientifique, 13274 Marseille Cedex 2, France, J. Sound Vib., 56 (1), pp 97-103 (Jan 8, 1978) 10 refs

Key Words: Sound waves, Acoustic scattering, Fourier transformation

By using the Fourier transform of the system of equations and continuity conditions, the Fourier transform of the solution is obtained. This last function is decomposed into several terms which are identified as Fourier images of known functions. An exact representation of the scattered sound pressure field is obtained as a combination of the radiation of the image source and layer potentials. Approximations are given when the point spherical source is located on the interface.

78-1232

Resonance Theory of Elastic Wave Scattering From a Cylindrical Cavity

A.J. Haug, S.G. Solomon, and H. Überall
Appl. Physics Lab., Johns Hopkins Univ., Silver Spring, MD 20910, J. Sound Vib., 57 (1), pp 51-58 (Mar 8, 1978) 2 figs, 17 refs

Key Words: Wave diffraction, Elastic waves, Cavities, Cavity resonators

Resonant excitation of a fluid-filled cylindrical cavity in an elastic medium by an incident compressional wave is investigated on the basis of the resonance theory of nuclear scattering. The resonances may be analyzed by studying them separately in each partial wave of the normal-mode series.

78-1233

Scattering of P and S Waves by Spherical Inclusions and Cavities

D.L. Jain and R.P. Kanwal
Dept. of Mathematics, Pennsylvania State Univ., University Park, PA 16802, J. Sound Vib., 57 (2), pp 171-202 (Mar 22, 1978) 10 figs, 11 refs

Key Words: Compression waves, Secondary waves, Wave diffraction, Inclusions, Spherical cavities

The solutions are presented for six problems of the scattering of low frequency plane harmonic elastic P and S waves when they impinge on a movable or an immovable rigid spherical inclusion or a spherical cavity. In each problem, the scatterer is embedded in an infinite homogeneous isotropic elastic medium. Formulas are derived for the scalar wave functions, components of the displacement vectors, stress tensors, far field amplitudes, scattering cross-sections and dynamic stress intensity factors.

78-1234

Effects of Grazing Flow on the Steady-State Flow Resistance and Acoustic Impedance of Thin Porous-Faced Liners

A.S. Hersh and B. Walker
Hersh Acoustical Engrg., Chatsworth, CA, Rept. No. NASA-CR-2951, 80 pp (Jan 1978)
N78-17822

Key Words: Acoustic linings, Porous materials, Acoustic impedance

The effects of grazing flow on the steady state flow resistance and acoustic impedance of seven Feltmetal and three Rigimesh thin porous faced liners were studied. The steady-state flow resistance of the ten specimens was measured using standard fluid mechanical experimental techniques. The acoustic impedance was measured using the two microphone method.

78-1235

Design of Multi-Screen Flow Expanders for Noise Reduction

J. Sentek
Univ. of Mining and Metallurgy, Cracow, Poland, J. Sound Vib., 56 (4), pp 509-519 (Feb 22, 1978) 13 figs, 6 refs

Key Words: Exhaust systems, Noise generation, Noise reduction

A method is presented of designing an expander and selecting its flow characteristics, for an expander in which low velocities in individual stages can be arbitrarily chosen.

78-1236

Noise From Small Air Jets and a Quiet Valve

T.W. Lancey
Faculty of Mech. Engrg., California State Univ., Fullerton, CA 92634, J. Sound Vib., 57 (1), pp 35-40 (Mar 8, 1978) 6 figs, 10 refs

Key Words: Noise generation, Nozzles, Valves

Noise measurements of air jets of from 0.0794 to 0.635 cm diameter, with jet exit velocity varying from 54 to 244 m/s, to frequencies of 100 kHz are presented. Results are compared to those previously obtained for larger nozzles; acoustical power spectral density curves are found to be similar to those for the larger nozzles at like velocities. Results of a noise survey conducted near a 0.127 m line size quiet vent valve having approximately 20 000 square jets, 0.127 cm on a side are presented.

78-1237

Use of Coherence and Phase Data Between Two Receivers in Evaluation of Noise Environments

A.G. Piersol

Bolt Beranek and Newman, Inc., 21120 Vanowen St., Canoga Park, CA 91303, J. Sound Vib., 56 (2), pp 215-228 (Jan 22, 1978) 13 figs, 11 refs

Sponsored by NASA, Ames Research Center

Key Words: Noise source identification, Noise reduction, Coherence techniques, Phase data, Wind tunnel tests

In certain well defined cases, the angular location and contribution of a distant source to the noise at a receiver location can often be established by a simple evaluation of coherence and phase data between two closely spaced receiver transducers, coupled with reasonable assumptions concerning the physics of the receiver acoustic field. Although such techniques are well established in theory, they have not been widely applied to noise control engineering problems, probably because of various practical difficulties, including those posed by reverberation effects. The purpose of this paper is to outline the basic principles involved in the analysis procedure, and to illustrate its application in the presence of reverberation effects by using data from a wind tunnel noise evaluation experiment.

78-1238

Comparison of Highway Noise Prediction Models

K.J. Plotkin and R.G. Kunicki

Wyle Labs./Wyle Research, Arlington, VA, Rept. No. WR-76-25, EPA/550/9-77/355, 46 pp (May 1977)

PB-276 710/1GA

Key Words: Traffic noise, Noise prediction, Mathematical models

A review and comparison has been conducted of three highway noise prediction models: NCHRP, TSC, and Wyle. The first two are those approved by the Federal Highway Administration; the third was developed for EPA. The elements comprising each model are analyzed in detail, including basic formulation, vehicle noise levels, propagation, treatment of various road geometries, and shielding by barriers. Significant differences among the models were found. A series of charts is presented whereby differences among the models may be estimated for particular input data. Comparison between measured roadside levels and predictions from the three models are also presented.

78-1239

A Manual for the Review of Highway Noise Impact

B.H. Sharp, K.J. Plotkin, P.K. Glenn, and R.M. Slone, Jr.

Wyle Labs./Wyle Research, Arlington, VA., Rept. No. WR-76-24, EPA/550/9-77/356, 71 pp (May 1977)

PB-276 509/7GA

Key Words: Traffic noise, Noise prediction, Manuals and handbooks

A manual has been prepared which presents a procedure for reviewing noise impact of proposed highway projects. The manual reviews Federal Highway Administration policy for noise impact, and includes specific steps for reviewing environmental impact statements and noise study reports prepared for proposed highway projects. The noise policy of the Department of Housing and Urban Development and noise levels identified by the Environmental Protection Agency are also reviewed, so that a complete assessment of the impact of expected noise may be made. A noise prediction model, consisting of charts, nomograms, and simple equations, is presented so as to enable an independent check of predicted levels presented in an EIS. The noise model (which includes barriers) is itself suitable for predicting roadside noise levels.

78-1240

Shielding of Noise from Statistically Stationary Tr ffic Flows by Simple Obstacles

K.W. Yeow, N. Popplewell, and J.F.W. Mackay

Faculty of Engrg., Univ. of Malaya, Kuala Lumpur, Malaysia, J. Sound Vib., 57 (2), pp 203-224 (Mar 22, 1978) 6 figs, 10 refs

Sponsored by the National Res. Council of Canada

Key Words: Traffic noise, Noise barriers

The effect of neighboring, smooth obstacles on the sound generated by statistically stationary traffic movements is analyzed for simple but realistic practical situations. Dimensions of obstacles like buildings are assumed much larger than the predominant, A-weighted wavelength of traffic noise so that diffraction may be neglected.

78-1241

Two Point Correlations of Jet Noise

H.S. Ribner

Inst. for Aerospace Studies, University of Toronto, Downsview, Ontario, Canada M3H 5T6, J. Sound Vib., 56 (1), pp 1-19 (Jan 8, 1978) 12 figs, 23 refs

Key Words: Aircraft noise, Jet noise, Noise measurement, Correlation techniques

A large body of careful experimental measurements of two-point broad band correlations of far-field jet noise has been carried out and was briefly reported recently by Lucio Maestrello in NASA TM X-72835. The rather sharp directional lobes and marked absence of axisymmetry were striking and motivated the present effort to bring theory to bear. The model of jet-noise generation is an approximate version of an earlier work of Ribner, based on the foundations of Lighthill. The model incorporates isotropic turbulence superimposed on a specified mean shear flow, with assumed space-time velocity correlations, but with source convection neglected. The particular vehicle is the Proudman format, and the previous work (mean-square pressure) is extended to display the two-point space-time correlations of pressure. The shape of polar plots of correlation is found to derive from two main factors: the non-compactness of the source region, which allows differences in travel times to the two microphones -- the dominant effect -- and the directivities of the constituent quadrupoles -- a weak effect. The non-compactness effect causes the directional lobes in a polar plot to have pointed tips (cusps) and to be especially narrow in the plane of the jet axis.

RANDOM

78-1242

Computation of External Excited Random Oscillations of Solid Continua (Berechnung von fremderregten Zufallsschwingungen fester Kontinua)

K. Hennig, H. Friedrich, and L. Knöfel

Akademie der Wissenschaften der DDR, Zentralinstitut f. Mathematik und Mechanik, Maschinenbautechnik, 26 (11), pp 496-499 (Nov 1977) 5 figs, 10 refs

(In German)

Key Words: Random excitation, Continuum mechanics

Semidiscrete methods for the approximation of randomly excited continuum vibration problems are presented. In an example the effect of wind loads on a cantilever is calculated.

78-1243

A Theory of the Greatest Maximum Response of Linear Structures

N.A.N. Youssef and N. Popplewell

Dept. of Mech. Engrg., Univ. of Manitoba, Winnipeg, Canada, J. Sound Vib., 56 (1), pp 21-33 (Jan 8, 1978) 6 figs, 21 refs

Key Words: Random excitation, Maximum response, Dynamic response

A general theory is developed to estimate the greatest maximum response of linear structures subjected to deterministic or random excitations. The analysis utilizes the prolate spheroidal wave functions and the uncertainty principle. Such a technique is useful in checking the results of different methods, which may involve tedious calculations, for finding the response spectra of impulsive loads without knowing the load shape, or in designing seismic structures. The applications are illustrated by simple vibrating oscillators exposed to short or long duration loads.

SEISMIC

(See Nos. 1217, 1221, 1222, 1225, 1227, 1323, 1332, 1334, 1335, 1336)

SHOCK

(Also see Nos. 1298, 1320)

78-1244

Equipment-Structure Interaction at High Frequencies

J.M. Kelly and J.L. Sackman

Weidlinger Associates, Menlo Park, CA, Rept. No. PR-7702, DNA-4298T, AD-E300 036, 72 pp (Apr 1, 1977)

AD-A049 065/6GA

Key Words: Interaction: structure-foundation, Missile silos, Protective shelters, Ground shock

A series of idealized models are considered which incorporate the characteristics of an embedment media, a structure and internal equipment. The equipment has natural frequencies which are high compared with the fundamental frequency of the structure. The purpose of the analysis is to obtain exact solutions to the idealized model. These may eventually be compared with solutions obtained by standard structural dynamics techniques to improve understanding of the degree of refinement needed in modeling and to provide guidance for selecting appropriate numerical integration techniques.

78-1245

Shock-Hardness Assessment of Submarine Equipment. Part IV - Interaction Phenomena in Shock Responses of Structures

R.L. Bort

Naval Research Lab., Washington, D.C., Rept. No. NRL-MR-3673, AD-E000 101, 54 pp (Dec 1977) AD-A049 449/2GA

Key Words: Interaction: structure-media, Shipboard equipment response, Underwater explosions, Buildings, Seismic response

Examples of the significance of structural interactions on the dynamic responses of structures are shown. The examples emphasize how reliance on calculated responses of massless oscillators can provide apparently-valid requirements for dynamic design of structures which are too large by orders of magnitude. Most examples are from the response of shipboard equipment to shock from underwater-explosion attacks but similarities in the response of buildings to earthquakes are pointed out.

78-1246

Finite Dynamic Expansion of a Cylindrical Cavity in a Hyperelastic Medium

A. Mioduchowski and J.B. Haddow

Dept. of Mech. Engrg., Univ. of Alberta, Edmonton, Alberta TGG 2E1, Canada, Ing. Arch., 47 (1), pp 21-26 (1978) 5 figs, 4 refs

Key Words: Shock wave propagation, Elastic media

A *numerical method* is proposed for the analysis of the finite cylindrically symmetric expansion of a cylindrical cavity in an unbounded isotropic hyperelastic compressible medium. Results obtained for a sudden application of pressure at the cavity surface are presented for a particular strain energy function.

78-1247

The Impact of an Elastic Cylinder on an Elastic Solid

H. Matsumoto, I. Nakahara, and Y. Matsuoka

Tokyo Inst. of Tech., Tokyo, Japan, Bull. JSME, 21 (154), pp 579-586 (Apr 1978) 6 figs, 13 refs

Key Words: Bars, Halfspace, Elastic properties, Impact response (mechanical), Shock wave propagation

The problem of the collision of an elastic cylinder onto an elastic solid is studied theoretically and experimentally. The effects of the material constants and the contact area *on the time history* of the impact load are analyzed based on the dynamic theory of elasticity for the solid and on the one dimensional theory of wave propagation for the cylinder.

PHENOMENOLOGY

COMPOSITE

78-1248

Dynamic Mechanical Behavior of Composite Material Under Sustained Sinusoidal Stresses

C. Hong

Ph.D. Thesis, The Pennsylvania State Univ., 120 pp (1977)

UM 7803331

Key Words: Composites, Laminates, Dynamic stability

This study is concerned with the determination of dynamic properties of a glass fiber reinforced material. Effects of fiber orientations, temperature, the magnitude of static biaxial stress and frequencies of sinusoidal stresses on dynamic properties have been studied. Also, a dynamic biaxial testing machine was developed for the measurement of dynamic properties of fiber reinforced materials for a low frequency range. Secondly, the resonant strength criterion based on the fatigue strength and the loss coefficient of the composite material has been developed. The energy dissipated in the adhesive double lap joint was obtained.

DAMPING

78-1249

A Study on Damping Capacity of a Jointed Cantilever Beam (1st Report; Experimental Results)

N. Nishiwaki, M. Masuko, Y. Ito, and I. Okumura

Tokyo Univ. of Agriculture & Tech., Koganei-City, Tokyo, Japan, Bull. JSME, 21 (153), pp 524-531 (Mar 1978) 21 figs, 5 refs

Key Words: Joints (junctions), Machine tools, Cantilever beams, Vibration damping, Expurimental data

The heavy machine tools are often made of welded steel and at the same time a jointed beam or a damping joint is often used. In this paper, the relationships between the frequency and the damping capacity or the slip ratio and between the damping capacity and the mode of vibration have been experimentally studied.

78-1250

An Introduction to the Problem of Dynamic Structural Damping

P. Santini

AGARD, Paris, France, Rept. No. AGARD-R-663; ISBN-92-835-1268-5, 24 pp (Jan 1978)
N78-17074

Key Words: Damping, Mathematical models, Coupled response

Major topics in the area of dynamic damping are described. A list of typical problems where damping is of primary importance is provided. Typical structural components are considered and a brief account on the effect of materials is given. Mathematical models and intermodal coupling are also examined, and the extreme difficulty of obtaining reasonably accurate information from them is emphasized. Possible philosophies of ground tests and flight tests are discussed.

78-1251

The Damping Effect of an Impact Damper

K. Yasuda and M. Toyoda

Faculty of Engrg., Nagoya Univ., Chikusa-ku, Nagoya, Japan, Bull. JSME, 21 (153), pp 424-430 (Mar 1978) 14 figs, 6 refs

Key Words: Impact dampers, Damping effects, Natural frequencies, Machinery vibration

Impact dampers are sometimes used for reducing vibrations of machines and structures. The damping effect of this type of damper on natural vibrations is investigated experimentally. The damping effect of a combined damper made up of two impact dampers was investigated.

78-1252

A Proportionate Coulomb and Viscously Damped Isolation System

W.A. Bullough and M.B. Foxon

Dept. of Mech. Engrg., Univ. of Sheffield, Sheffield S1 3JD, UK, J. Sound Vib., 56 (1), pp 35-44 (Jan 8, 1978) 12 figs, 8 refs

Key Words: Viscous damping

The results of a computer study aimed at assessing the usefulness of a controllable, variable effect, non-linear damper in a vibration isolation system are given. This is done by showing the effect on the performance of a simple model suspension system of the addition of a controllable spring/damper link. The damping characteristic of the controllable element is that of a viscous damper with a threshold force required to move it; the viscous rate is fixed whilst the threshold force is pre-selected.

78-1253

Analysis of Coulomb Friction Vibration Dampers

D.W. Alspaugh

School of Aeronautics and Astronautics, Purdue Univ., West Lafayette, IN 47907, J. Sound Vib., 57 (1), pp 65-78 (Mar 8, 1978) 17 figs, 4 refs

Key Words: Coulomb friction, Vibration damping, Periodic response

An analysis of the steady state response of a rotational Coulomb friction vibration damper has been carried out. Such dampers are sometimes used in various industrial applications. Analysis of the steady state phase plane is used to determine various response quantities such as amplitude ratio, phase lag, energy dissipated per cycle, and rms power loss. The analysis shows that the response can be categorized into one of three main types. Expressions are developed to predict effect of the addition of a damper on the power and the disturbance amplitude transmitted to the load.

FLUID

(Also see Nos. 1308, 1328, 1350)

78-1254

Identification of Modes in Some Conditions of Sound Propagation in Shallow Water

C. Gazanhes, J.P. Sessarego, and J.L. Garnier

Dept. of Acoustics, Centre National de la Recherche Scientifique, 13274 Marseille Cedex 2, France, J. Sound Vib., 56 (2), pp 251-259 (Jan 22, 1978) 10 figs, 1 table, 8 refs

Key Words: Underwater sound, Sound propagation

Pekeris' theory, concerning problems of sound propagation in shallow water, has been used to study the possibilities of a spatial filtering of some modes. In this study a particular set of receivers and signal processors have been tested experimentally for different propagation conditions, with the use of a reduced scale model satisfying Pekeris' hypotheses.

78-1255

Approximate Methods in Fluid-Structure Interaction Problems

A.V. Clark, Jr.

Ph.D. Thesis, Univ. of Pennsylvania, 88 pp (1977)

UM 7806566

Key Words: Interaction: structure-fluid

Some approximate methods of calculating the response of structures submerged in an infinite acoustic fluid are considered.

78-1256

Development and Application of an Optimization Procedure for Flutter Suppression Using the Aerodynamic Energy Concept

E. Nissim and I. Abel

Technion-Israel Inst. of Tech., Rept. No. NASA-TP-1137; L-11909, 39 pp (Feb 1978)

N78-18459

Key Words: Flutter, Vibration control, Wind induced excitation

An optimization procedure is developed based on the responses of a system to continuous gust inputs. The procedure uses control law transfer functions which have been partially determined by using the relaxed aerodynamic energy approach. The optimization procedure yields a flutter suppression system which minimizes control surface activity in a gust environment. The procedure is applied to wing flutter of a drone aircraft.

EXPERIMENTATION

BALANCING

78-1257

Balancing of Rotating Systems During Operation

J. Van De Vegte and R.T. Lake

Dept. of Mech. Engrg., Univ. of Toronto, Toronto, Ontario, Canada, J. Sound Vib., 57 (2), pp 225-235 (Mar 22, 1978) 8 figs, 1 table, 1 ref

Key Words: Balancing techniques, Rotating structures, Rotors, Generators, Turbines, Fans, Pumps, Compressors

A system has been developed and tested for the balancing of rotating systems without interrupting operation. Several procedures are proposed for balancing, in which only measurements of the bearing vibrations are used. Large generators, turbines, fans, pumps, and compressors are potential applications.

DIAGNOSTICS

(Also see No. 1348)

78-1258

Design of a Signature Analysis System for Product and Machinery Condition Monitoring

W.H. Dornfeld

Ph.D. Thesis, The Univ. of Wisconsin-Madison, 233 pp (1977)

UM 7728243

Key Words: Acoustic signatures, Diagnostic techniques

A systematic approach is developed for the design of a signature analysis system for either on-line product quality assurance or plant machinery condition monitoring. The proposed approach involves the following steps: acquiring an understanding of the physical nature of the device to be analyzed, identifying generating phenomena which reflect the operating condition of the device, choosing a measurable signal or signals which directly or indirectly result from the generating phenomena, observing the signals or their transformations for each condition of operation, specifying unique signature features of the signals or transformed signals, selecting computable measures which describe feature characteristics as scalar quantities, developing a decision routine or thresholds for classifying each operating condition using the scalar measures, and verifying and/or improving the reliability of the developed system.

78-1259

Centralized Vibration Diagnostic Facility at Fawley Power Station

Noise Control Vib. Isolation, 9 (3), pp 102-103 (Mar 1978) 3 figs

Key Words: Diagnostic instrumentation, Nuclear power plants, Rotating structures

An automatic rundown vibration data acquisition system is described. In it the Vibro-Meter was selected to supply a system employing piezoelectric accelerometers with integral electronics and heavy duty stainless steel water-proof flexible conduit tubing.

78-1260

Helicopter Health Monitoring

N.E. Trigg

Helitune, Ltd., Noise Control Vib. Isolation, 9 (3), pp 91-97 (Mar 1978) 13 figs

Key Words: Diagnostic techniques, Helicopter rotors

The author examines the various techniques used on helicopters for engine and gearbox surveillance, considers main and tail rotor balancing and tracking, and the very latest method of vibration signature analysis and monitoring.

78-1261

Vibration Spectrum Analysis: Foolproof Quality Control

Power Transm. Des., 20 (4), p 55 (Apr 1978) 3 figs

Key Words: Diagnostic instrumentation, Spectrum analyzers

The application of a real-time spectrum analyzer to the diagnostics of mechanical or electromechanical devices is described.

78-1262

Early Warning System for Rotating Equipment

Diesel Gas Turbine Prog., 34 (5), pp 64-65 (May 1978) 4 figs

Key Words: Diagnostic instrumentation, Wave analyzers, Torsional vibrations, Vibration signatures, Rotating structures

Two instruments for in-field measurement of torsional vibration, which use the F-M technique and incorporate a wave analyzer are described. They are a torsional order analyzer and a vibration signature analyzer. They accept inputs from magnetic as well as optical encoders, and analyze the different engine orders in units of peak angular displacement. The unit uses a narrow bandpass filter that locks onto the programmed order or half order and then tracks it through two selectable rpm ranges.

78-1263

Signature Analysis Systems with Fourier Analyzer

Noise Control Vib. Analysis, 9 (3), pp 81-83 (Mar 1978) 10 figs

Key Words: Diagnostic instrumentation, Fourier analysis, Signal processing techniques, Rotating structures

Solution of noise, vibration, and failure problems by using a signature analysis package with a Fourier analyzer are described. The system measures signals generated by rotating machinery, stores these signals (or signatures) on a magnetic disc, analyzes the data and plots the information in a variety of formats. Intended for those who build, test or use rotating and reciprocating machinery, the signature analysis system can be applied to design analysis, production quality control, preventive maintenance and noise and vibration studies.

INSTRUMENTATION

78-1264

Pseudo Continuous Wave Acoustic Instrument

J.S. Heyman

Langley Res. Center, NASA, Langley Station, VA, Rept. No. NASA-Case-LAR-12260-1; US-Patent-Appl-SN-858763, 12 pp (Dec 8, 1977)
N78-17821

Key Words: Acoustic measuring instruments

A device for measuring acoustic properties and their changes in a sample of liquid, gas, plasma or solid is described. A variable frequency source is applied to the sample by means of a transducer to produce sound waves within the sample. The application of the variable frequency source to the sample is periodically interrupted for a short duration.

78-1265

Amplitude and Statistical Distribution Analyzers

A.L. Stolberg

Metrosonics, Inc., Rochester, NY, S/V, Sound Vib., 12 (3), pp 56-57 (Mar 1978) 7 figs

Key Words: Noise measurement, Measuring instruments, Statistical analysis

The article discusses statistical distribution analyzers which are sophisticated instruments designed to gather sound level data and automatically compute amplitude descriptors. Basically they are a combination of sound-level meters and digital processors. Acoustical signals are amplified and weighted in an analog format as in a sound-level meter. The signals are then converted to digital format for computer analysis and storage. Amplitude and statistical distribution analyzers are used for measuring the fluctuating environmental noise, such as traffic or occupational noise, requiring a statistical approach for meaningful correlations.

78-1266
Noise Dosimeter Update
J.P. Seiler
Mine Safety and Health Administration, Pittsburgh, PA, S/V, Sound Vib., 12 (3), pp 32-33 (Mar 1978) 1 table

Key Words: Noise measurement, Measuring instruments, Standards

During the past year, a number of new dosimeters have appeared commercially, a number of old dosimeters have been discontinued, new evaluations of various dosimeters have been conducted and published, and work has continued on defining, designing and testing a time resolved dosimeter. Also, work is continuing in the development of an ANSI dosimeter standard, and various governmental agencies have incorporated dosimeters into their noise exposure monitoring programs. This article will discuss the current state of each of these topics.

78-1267
Sound-Level Meters
J.M. Steele
GenRad, Inc., Bolton, MA, S/V, Sound Vib., 12 (3), pp 30-31 (Mar 1978) 1 fig, 3 refs

Key Words: Sound level meters, Standards, Measuring instruments

Frequently, the applied accuracy of a precision or general purpose sound-level meter is not as good as the accuracy that the user may expect, based on the standards that control the sound-level meter. The poorer accuracy may be caused by the nature of the signal to be measured, or be a result of limitations of the instrument, measurement technique of the user, or the environment in which the measurement is made. These limitations are examined in detail.

78-1268
Performance Characteristics and the Selection of Accelerometers
J. Wilson
Endevco, San Juan Capistrano, CA., S/V, Sound Vib., 12 (3), pp 24-29 (Mar 1978) 6 figs

Key Words: Accelerometers, Vibration measurement, Measuring instruments

Basic accelerometer characteristics needed in the attainment of high fidelity shock and vibration test data are discussed. They are the mass loading errors, mounting effects on performance, transverse sensitivity, amplitude range and linearity, sensitivity change with temperature, transducer strain effects, transient temperature effects on the transducer, acoustic noise, and RF and magnetic fields.

78-1269
Everything You've Wanted to Know About Measurement Microphones
W.R. Kundert
GenRad, Inc., Bolton, MA, S/V, Sound Vib., 12 (3), pp 10-23 (Mar 1978) 26 figs, 6 tables

Key Words: Measuring instruments, Microphones

The purpose of this article is to acquaint the reader with the performance, environmental characteristics, and applications of three basic types of measurement microphones: the piezoelectric ceramic or "ceramic," air-condenser or "condenser," and electret-condenser or "electret," with a particular emphasis on the latter. The relative importance of these characteritics for a given application must be understood before an informed choice of type and size can be made.

78-1270
Portable Tape Recorders
J. Hassall and M. Bonnett
Brüel & Kjaer, Denmark, S/V, Sound Vib., 12 (3), pp 58-59 (Mar 1978) 5 figs

Key Words: Recording instruments

Over the years a number of recording techniques have been developed. Of these the "Direct" and "Frequency Modulation" techniques have been well established for instrumentation purposes. The basic principles essential to an understanding of these techniques as well as their advantages and disadvantages are reviewed.

78-1271
An Integrating Real-Time Analyzer
D.S. Allen
GenRad, Inc., Bolton, MA., S/V, Sound Vib., 12 (3), pp 4-6 (Mar 1978) 5 figs

Key Words: Vibration analyzers, Noise measurement

A new integrating real-time analyzer is described which has a built-in CRT display, weighs 40 pounds, is battery operated and brings added convenience to noise measurement and analysis. It is a one-third-octave and full-octave real-time analyzer with long-term integration facilities. It operates as an integrating analyzer or integrating sound-level meter to display A- or C-weighted sound level or any selected band level as a function of time. Either ac power or internal battery pack can be used to power the instrument.

78-1272

Amplitude Accuracy Limitations of Real-Time Single Channel Spectrum Analyzers

J. Flink
Rockland Systems Corp., West Nyack, NY, S/V,
Sound Vib., 12 (3), pp 52-54 (Mar 1978) 3 figs, 2 tables

Key Words: Spectrum analyzers, Measuring instruments

Modern spectrum analyzers do not measure amplitude as accurately as might be assumed because they contain special-purpose computers to implement mathematical algorithms, e.g., spectrum analysis via the Fast Fourier Transform (FFT) and smoothing is done using digital averaging. The fundamental errors discussed are the picket fence effect, the effect of windowing, and the effect of smoothing voltage or log amplitude spectra rather than power spectra. Hardware factors that contribute to the amplitude error are also examined and then the amplitude accuracy of a modern spectrum analyzer is compared to a sweeping spectrum analyzer which is implemented using analog techniques.

78-1273

Spectrum Analyzers

R. Upton
Brüel & Kjaer, Denmark, S/V,
Sound Vib., 12 (3), pp 36-38 (Mar 1978) 3 figs

Key Words: Spectrum analyzers, Measuring instruments

This article surveys some of the types of spectrum analyzers available, and examines factors which will influence their choice for particular measurement problems.

78-1274

Advantages of High Real Time FFT Analyzers

A.C. Keller
Spectral Dynamics Corp., San Diego, CA., S/V,
Sound Vib., 12 (3), pp 48-51 (Mar 1978) 16 figs

Key Words: Frequency analyzers, Fast Fourier transform, Measuring instruments

Some of the not so obvious advantages and applications of high real-time rate are explored in this discussion. Three interrelated concepts should be considered when one thinks of real-time rate. The first, high real-time analysis speed, assures no loss of data up to the real-time rate and, more importantly, assures that data will not be analyzed incorrectly because of insufficient speed. Second, a fast display rate allows the analyzer or processor to display things which are happening on an updated basis. Phenomena, such as beating frequencies, machine speed changes, turbine blade resonances and non-stationary data which might otherwise be smeared or averaged into the display, may be observed. Overlap processing, the third concept, which is the ability to perform a selected analysis function before a whole new memory sampling interval has elapsed, is only possible where a high real-time analysis rate is available. Using overlap processing the analyst is able to monitor changing phenomena, on a continuous basis, such as during impact testing, to provide optimum signal-to-noise enhancement and to utilize weighting and windowing functions to their optimum benefit.

78-1275

Introduction to Wave Analysis Instruments

J.G. Bollinger
Univ. of Wisconsin-Madison, Madison, WI, S/V,
Sound Vib., 12 (3), p 34 (Mar 1978) 1 table

Key Words: Wave analyzers, Measuring instruments

A brief description and a table is presented, which establishes broad guidelines for selecting the proper wave analysis instrumentation for some typical problems.

SCALING AND MODELING

78-1276

A Scale Model Technique for Investigating Traffic Noise Propagation

M.E. Delany, A.J. Rennie, and K.M. Collins
Div. of Radiation Science and Acoustics, National Physical Lab., Teddington TW11 0LW, UK,
J. Sound Vib., 56 (3), pp 325-340 (Feb 8, 1978) 10 figs, 28 refs

Key Words: Traffic noise, Scaling, Model testing

A 30:1 scale model technique has been developed for investigating the propagation of noise from traffic on major roads and motorways. Validation studies have been carried out for a range of different road/housing configurations by comparing relative noise levels obtained using the model with field data obtained specifically for the purpose. This model has been used to obtain systematic prediction data

and examples are shown for noise propagating from a road in a natural cut, noise penetration through a gap between adjacent blocks of houses, and containment effects associated with unbroken parallel building facades on opposite sides of the road.

TECHNIQUES

(Also see No. 1263)

78-1277

Development of an Impulse Technique for Measurement of Muffler Characteristics

R. Singh and T. Katra

Acoustics/Dynamics Engrg., Carlyle Compressor Co., Div. of Carrier Corp., Syracuse, NY 13221, J. Sound Vib., 56 (2), pp 279-298 (Jan 22, 1978) 18 figs, 30 refs

Key Words: Engine mufflers, Testing techniques, Acoustic techniques

This paper describes an acoustic impulse technique for an experimental evaluation of mufflers. An acoustic impulse of short duration is generated and applied to the muffler specimen. Isolated incident, reflected and transmitted pulses are captured by appropriately located pressure transducers. A synchronous time domain averaging operation is performed to eliminate random flow noise components from these pressure signals. Desired muffler characteristics are then computed, in the frequency domain, from the Fourier transforms of the isolated wave time histories. Both magnitude and phase are obtained as continuous functions of frequency (with resolution limited only by the available computing facility).

78-1278

An Efficient Method of Measuring Impedances of Fluid Machinery Manifolds

R. Singh and W. Soedel

School of Mech. Engrg, Ray W. Herrick Labs., Purdue Univ., West Lafayette, IN 47907, J. Sound Vib., 56 (1), pp 105-125 (Jan 8, 1978) 22 figs, 1 table, 18 refs

Key Words: Acoustic impedance, Manifolds, Fluid-induced excitation, Measurement techniques

Knowledge of the acoustical impedances is required to understand the fluid oscillations in the manifolds of positive displacement machinery. This paper presents an impedance measurement method which puts emphasis on the lower frequencies. The technique is based on providing a known volume velocity excitation to the manifold through an electrodynamic, shaker driven, oscillating piston. Harmonic, random and transient excitations have been utilized. Digital data acquisition and processing techniques are used to acquire piston displacement and acoustic pressure signals for input and transfer impedances. The proposed method is direct and efficient. It is applied to the measurement of the acoustical impedances of a two-cylinder refrigeration compressor discharge system. Various aspects of the measurement procedures are discussed along with the recommendations.

78-1279

Measurements with an Intensity Meter of the Acoustic Power of a Small Machine in a Room

F.J. Fahy

Inst. of Sound and Vibration Res., Univ. of Southampton, Southampton S09 5NH, UK, J. Sound Vib., 57 (3), pp 311-322 (Apr 8, 1978) 6 figs, 4 tables, 6 refs

Key Words: Acoustic measurement, Measurement techniques

A technique in which two closely spaced pressure microphones, a special purpose circuit, and a sound level meter are employed to measure acoustic intensity in octave bands, is used to estimate the intensity distribution around a small, 1200 electrical watt, machine situated in a room. The total acoustic power estimated therefrom is compared with that obtained by the conventional "direct field" method. The technique, which appears to be accurate over the range 250-4000 Hz, produces values of intensity and power which are generally less than the "direct field" values. The difference tends to increase with frequency. A potential for source location application is indicated.

HOLOGRAPHY

78-1280

Holographic Visualization of Acoustic Fields

J.A. Clark

Acousto-Optics Lab., Catholic Univ. of America, Washington, DC 20064, J. Sound Vib., 56 (2), pp 167-174 (Jan 22, 1978) 4 figs, 9 refs

Sponsored by Office of Naval Research

Key Words: Acoustic holography

Optical holographic visualization of sound is demonstrated. Instantaneous pressure distributions are determined from patterns of optical interference fringes which appear in reconstructed images of sound fields. If the acoustic pressure is constant in one direction, the interference fringes can be interpreted in a particularly simple way: as contours of equal instantaneous acoustic pressure. A series of reconstructed images recorded at 20 microsecond intervals are presented which show the propagation of a 16 kHz acoustic toneburst in water. Results obtained with the new holographic visualization method are compared with those of classical schlieren visualization methods.

COMPONENTS

SHAFTS

(See No. 1358)

BEAMS, STRINGS, RODS, BARS

(Also see Nos. 1215, 1247, 1249, 1346)

78-1281

Blast Response of UHF Polemast Antenna-Event Dice Throw

C.G. Coffey and G.V. Price
Defence Res. Establishment, Suffield, Ralston, Alberta, Canada, Rept. No. DRES-TECHNICAL PAPER-449, 52 pp (Nov 1977)
AD-A049 524/2GA

Key Words: Antennas, Ships, Nuclear explosion effects

The blast response of a 23 ft UHF Polemast Antenna was investigated in a free-field blast trial and in numerical simulation experiments.

78-1282

Finite Element Eigenvalue Analysis of Tapered and Twisted Timoshenko Beams

R.S. Gupta and S.S. Rao
Dept. of Mech. Engrg., Punjab Engineering College, Chandigarh-11, India, J. Sound Vib., 56 (2), pp 187-200 (Jan 22, 1978) 6 figs, 2 tables, 22 refs

Key Words: Cantilever beams, Beams, Timoshenko theory, Finite element technique

The stiffness and mass matrices of a twisted beam element with linearly varying breadth and depth are derived. The angle of twist is assumed to vary linearly along the length of the beam. The effects of shear deformation and rotary inertia are considered in deriving the elemental matrices. The first four natural frequencies and mode shapes are calculated for cantilever beams of various depth and breadth taper ratios at different angles of twist. The results are compared with those available in the literature.

78-1283

Free Vibration of Neutrally Buoyant Inflatable Cantilevers in the Ocean Environment

V.J. Modi and D.T. Poon
The Univ. of British Columbia, Vancouver, B.C., Canada, J. Hydronautics, 12 (2), pp 55-62 (Apr 1978) 4 figs, 1 table, 33 refs

Key Words: Free vibration, Cantilever beams, Floating structures, Inflatable structures

Free vibration analysis of the neutrally buoyant inflated cantilevers, made of plastic sandwiched films, is presented, accounting for the added inertia and nonlinear hydrodynamic drag. The significant feature of the analysis is the reduction of the shell equations (the membrane, Flügge's, and Herrmann-Armenákas') into a single equation which is similar in form to that for a vibrating beam with rotary inertia effects. The natural frequencies obtained are compared with the experimental results and those predicted by the Rayleigh-Ritz method in conjunction with the Washizu and membrane shell theories.

78-1284

Natural Frequencies of Radial Rotating Beams

S. Putter and H. Manor
Faculty of Mech. Engrg., Technion-Israel Inst. of Tech., Haifa, Israel, J. Sound Vib., 56 (2), pp 175-185 (Jan 22, 1978) 7 figs, 11 refs

Key Words: Beams, Rotating structures, Cantilever beams, Natural frequencies, Finite element technique

Lead-lag natural frequencies and mode shapes of a radial beam mounted on a rotating disc at a 90° setting angle are determined. The solution was obtained by means of the finite element technique, a high precision beam element based on a fifth degree polynomial being used as displacement function, with deflection and slope at the ends as common nodal degrees of freedom, and two integrals over the element length as nodeless additional degrees of freedom. Effects such as shearing force, rotary inertia and varying centrifugal forces are taken into consideration. The case of a beam blade with shroud mass is also considered.

78-1285

Simulation and Experimental Studies of Heat Exchanger Tube Vibration with Clearance Support Interaction

R.J. Rogers

Ph.D. Thesis, Univ. of Waterloo (Canada) (1977)

Key Words: Beams, Supports, Heat exchangers, Rotatory inertia effects, Transverse shear deformation effects, Computer programs

A technique has been developed to simulate the transient response of a beam-like structure such as a heat exchanger tube as it interacts with its clearance supports. The detailed dynamic interaction between the beam and its supports is predicted, thus providing the contact forces and other variables useful in predicting rates of wear. The method uses 3-dimensional beam finite elements which include the effects of shear deformation and rotational inertia.

78-1286

Dynamic Behaviour of a Beam Subjected to a Force of Time-Dependent Frequency

S.-I. Suzuki

Dept. of Aeronautics, Nagoya Univ., Nagoya, Japan, J. Sound Vib., 57 (1), pp 59-64 (Mar 8, 1978) 7 figs, 2 refs

Key Words: Beams, Dynamic response, Time-dependent excitation, Forced excitation, Resonant frequency

It is a well-known fact that, for an ideal system in which damping is ignored, the deflection of a beam becomes infinite for the case where the constant frequency of a steady-state external force is equal to the critical frequency of the beam. In this paper, the external force is assumed to be proportional to $\sin(at^2/2 + bt^3/3)$ with respect to time, where a and b are constants, and the effect of time-dependent frequency on the dynamic behavior of the beam is investigated. Integrations involved in the theoretical results are carried out by Simpson's rule.

78-1287

Some Optimization Problems in Torsional Vibration

M.H.S. Elwany and A.D.S. Barr

Dept. of Mech. Engrg., Univ. of Dundee, Dundee DD1 4HN, UK, J. Sound Vib., 57 (1), pp 1-33 (Mar 8, 1978) 18 figs, 12 tables, 16 refs

Key Words: Beams, Torsional vibration, Natural frequency, Optimization

The design of beams to maximize a torsional natural frequency for a given total mass is considered. The beams analyzed are in the main cantilevered and of rectangular cross section but the theory is easily extended to other end conditions and section shapes. A variety of cases is considered involving the inclusion of upper or lower bounds on the section dimensions or the addition of a concentrated end inertia.

78-1288

Calculation of Integrals Involving Characteristic Beam Functions

C.B. Sharma

Dept. of Mathematics, Univ. of Manchester Inst. of Science and Tech., Manchester M60 1QD, UK, J. Sound Vib., 56 (4), pp 475-480 (Feb 22, 1978) 1 table, 4 refs

Key Words: Beams, Cylindrical shells

An analytical procedure is presented for evaluating some important integrals involving characteristic beam functions. These integrals were encountered in the vibration analyses of constrained and unconstrained circular cylindrical shells. The analysis will also be useful in many other problems where characteristic beam functions are involved and will enable complicated and computer-time-consuming numerical integration to be avoided.

78-1289

Dynamic Behavior of a Load Lifted by a Mobile Construction-type Crane (5th Report. The Investigation of Dynamic Load Factors)

H. Ito, Y. Senda, H. Fujimoto, and Y. Kato

Kobe Steel Ltd., Akashi, Japan, Bull. JSME, 21 (154), pp 609-617 (Apr 1978) 16 figs, 5 tables, 4 refs

Key Words: Cranes (hoists)

In this paper, various simulation models of cranes are shown. Formulas for dynamic load factors using multiple regression analysis are established. These approximate formulas are simple polynomials in which basic dimensions of crane are variables, and they are found satisfactory enough for any practical application.

78-1290

Natural Frequencies of Two Cantilevers Joined by a Rigid Connector at Their Free Ends

G.L. Anderson

Institut CERAC SA, CH-1024 Ecublens, Switzerland,

J. Sound Vib., 57 (3), pp 403-412 (Apr 8, 1978) 5 figs, 9 refs

Key Words: Cantilever beams, Natural frequencies

The derivation of the equations of motion is given for a system consisting of two identical parallel cantilevers joined by a rigid connector at their free ends. Elementary beam theory is employed, and it is observed that the longitudinal and flexural deformations of the system are coupled through the boundary conditions but not through the differential equations. The associated free vibration problem is solved.

78-1291

The Effect of Rotary Inertia and Shear Deformation on the Frequency and Normal Mode Equations of Uniform Beams Carrying a Concentrated Mass

D.A. Grant

Dept. of Mech. Engrg., Univ. of Maine, Orono, ME 04473, J. Sound Vib., 57 (3), pp 357-365 (Apr 8, 1978) 2 figs, 5 refs

Key Words: Rotatory inertia effects, Transverse shear deformation effects, Beams, Frequencies, Normal modes

New frequency equations for transverse vibrations of Timoshenko beams carrying a concentrated mass at an arbitrary point along the beam are given. Normal mode equations for the hinged-hinged beam are given and the orthogonality condition is presented for beams with hinged, clamped or free ends. A numerical example is given and frequency charts show the effects of varying the size and location of the concentrated mass.

78-1292

Direct Analytical Solutions to Non-Uniform Beam Problems

C.D. Bailey

Dept. of Aeronautical and Astronautical Engrg., The Ohio State Univ., Columbus, OH 43220, J. Sound Vib., 56 (4), pp 501-507 (Feb 22, 1978) 2 figs, 5 tables, 13 refs

Sponsored by NASA Langley Research Center

Key Words: Beams, Vibration response

The direct analytical solution to the vibration of non-uniform beams with and without discontinuities and with various boundary conditions is presented. Results are compared to results from the exact solution for certain cases where the exact solution has been obtained.

BLADES

78-1293

Design of Propellers for Minimum Noise

C.-J. Woan

Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 205 pp (1977)

UM 7804196

Key Words: Propellers, Noise reduction, Design techniques

The investigation is concerned with the theoretical design of propeller to obtain minimum noise, subject to constrains on the aerodynamic performance and wake configuration. In this analysis, which is based on both acoustic and aerodynamic considerations, attention is given only to the rotational noise due to static sources.

78-1294

Torsional Flutter in Stalled Cascade

S. Yashima and H. Tanaka

Aircraft Engine Div., Ishikawajima-Harima Heavy Industries, Tokyo, Japan, J. Engr. Power, Trans. ASME, 100 (2), pp 317-325 (Apr 1978) 14 figs, 13 refs

Key Words: Compressor blades, Flutter, Torsional vibration

Applying free streamline theory and singularity method, a theoretical study is developed for the torsional flutter problem in fully stalled cascade. Aerodynamic moment acting on a vibrating blade is calculated for some cascade conditions. Experiments were carried out using a water tunnel with a linear cascade, and the unsteady moment acting on the vibrating blade was measured. Computational and experimental results are compared.

78-1295

Investigation of Blade Vibrations Concerning Impellers of Highly Loaded Radial Compressors by Means of Telemetry (Zur Untersuchung von Schaufelschwingungen an Läufradern hochbelasteter Radialverdichter mittels Datentelemetrie)

U. Haupt and M. Rautenberg

Institut f. Strömungsmaschinen der TU Hannover, Hannover, Germany, MTZ Motortech. Z., 39 (4), pp 177-183 (Apr 1978) 10 figs, 10 refs

(In German)

Key Words: Compressor blades, Vibration measurement

The increase of small gas turbines and turbochargers led to the development of highly loaded radial compressors with thin blades. Various blade vibration problems are investigated in the first part of the article. Then blade vibrations of a radial compressor impeller are examined. Semiconductor strain gages are used to measure the strain on blades in different operating ranges of the compressor, like rotating stall, surge and flutter ranges and for the case of non uniform flow conditions downstream and upstream the impeller. The signals are transmitted by a 12 channel-telemetry system.

78-1296

Synthesis of Blade Flutter Vibratory Patterns Using Stationary Transducers

A. Kurkov and J. Dicus

Lewis Res. Center, NASA, Cleveland, OH, Rept. No. NASA-TM-73821; E-9410, 26 pp (Mar 1977) N78-17001

Key Words: Rotor blades, Flutter

Flutter frequency was determined and rotor vibratory amplitude and phase distributions during flutter were reconstructed from stationary aerodynamic type measurements. A previously reported optical method for measuring blade-tip displacement during flutter was extended by means of digital analysis. Displacement amplitudes and phase angles were determined based on this method. For selected blades, spectral results were also obtained from strain gage measurements. The results from these three types of measurement were compared and critically evaluated.

CONTROLS

78-1297

Stability Analysis of an Acceleration Governor Subjected to a Harmonic Speed Disturbance

D. Ardayfio

Dept. of Mech. Engrg., Univ. of Science and Tech., Kumasi, Ghana, Mech. Mach. Theory, 13 (2), pp 119-123 (1978) 3 figs, 8 refs

Key Words: Stability methods, Mechanisms, Control equipment

An inertia governor which is subjected to harmonic variations in rotational speed is analyzed in this paper. The equation of motion under such small speed harmonic variation is a Hill type equation. The perturbation-variation method is used to explicitly define the instability speed zones due to the parametric excitation. Numerical results illustrating the application of the analytic method are given for typical inertia governors.

CYLINDERS

78-1298

Torsional Impulsive Response of an Elastic Half-Space Due to a Rigid Circular Cylinder

H. Matsumoto, I. Nakahara, and M. Sekimoto

Tokyo Inst. of Tech., Tokyo, Japan, Bull. JSME, 21 (154), pp 572-578 (Apr 1978) 12 figs, 7 refs

Key Words: Cylinders, Half space, Elastic properties, Impact response (mechanical), Torsional response

The rigid circular cylinder cemented on an elastic half-space is rotated impulsively through a small angle. The problem is solved by setting up an integral equation for the Laplace transform of the coefficient of the stress function. The inversion of the Laplace transform is carried out by using the numerical method. The numerical results are shown for the impulsive response of the elastic half-space such as the stress intensity factor and the torque.

DUCTS

(Also see No. 1307)

78-1299

A Finite Element Method for Transmission in Non-Uniform Ducts without Flow: Comparison with the Method of Weighted Residuals

R.J. Astley and W. Eversman

Dept. of Mech. Engrg., Univ. of Canterbury, Christchurch, New Zealand, J. Sound Vib., 57 (3), pp 367-388 (Apr 8, 1978) 5 figs, 6 tables, 12 refs

Sponsored by NASA Lewis Research Center

Key Words: Ducts, Sound transmission, Finite element technique, Galerkin method, Method of weighted residuals

A finite element method is developed for the study of transmission of sound in nonuniform ducts without flow. The formulation is based on a weighted residuals approach and eight noded isoparametric elements are used. Two computational schemes are described, one based on the Helmholtz equation obtained by combining the basic conservation equations and one based on the conservation equations themselves.

78-1300

A Method of Weighted Residuals with Trigonometric Basis Functions for Sound Transmission in Circular Ducts

P.T. Vo and W. Eversman

Dept. of Mech. Engrg., Univ. of Canterbury, Christchurch, New Zealand, J. Sound Vib., 56 (2), pp 243-250 (Jan 22, 1978) 1 fig, 4 tables, 6 refs

Key Words: Ducts, Sound transmission, Galerkin method

A modified Galerkin method is employed to formulate the problem of transmission of sound in a uniform circular duct. The basis functions used are trigonometric and are derived from the equivalent problem in a two-dimensional duct. In the case when flow is present basis functions from the case without flow are used.

78-1301

Comparison of Measured Broadband Noise Attenuation Spectra from Circular Flow Ducts and From Lined Engine Intakes with Predictions

A.A. Syed and S.C. Bennett

Aero Div., Rolls-Royce Ltd., Derby DE2 8BJ, UK, J. Sound Vib., 56 (4), pp 531-564 (Feb 22, 1978) 32 figs, 5 tables, 33 refs

Key Words: Ducts, Sound propagation, Acoustic linings

Sound propagation in lined circular ducts is investigated in the presence of uniform and sheared flow. The modal solutions are obtained by solving an eigenvalue equation which, in the case of sheared flow, is derived by using finite differences and by matching the pressure and the radial component of the particle velocity at the interface of the regions of uniform and sheared flow. For the uniform flow region, standard Bessel function solutions are used. The attenuation of acoustic energy at a given frequency and for a given liner length is computed on the assumption that at the inlet to the lined duct, the acoustic energy is equally distributed among the propagating modes. In general very good agreement between predictions and measurements is obtained.

78-1302

A Reactive Acoustic Attenuator

C.R. Fuller and D.A. Bies

Dept. of Mech. Engrg., Univ. of Adelaide, Adelaide, South Australia 5000, J. Sound Vib., 56 (1), pp 45-49 (Jan 8, 1978) 11 figs, 5 refs

Key Words: Ducts, Noise reduction, Acoustic absorption

A reactive acoustic attenuator that combines high reflection of low frequency sound with low pressure drop coefficient is investigated experimentally and theoretically by using equations for sound propagation in straight and curved ducts. Good agreement is obtained and the theory is used to redesign the device to give a minimum transmission loss of ten decibels over a frequency range of three-quarters of an octave. Small discrepancies between theoretical and experimental results are discussed.

78-1303

Sound Generation and Transmission in Flow Ducts with Axial Temperature Gradients

A. Cummings

Inst. of Environmental Science and Tech., Polytechnic of the South Bank, London SE1 0AA, UK, J. Sound Vib., 57 (2), pp 261-279 (Mar 22, 1978) 8 figs, 13 refs

Key Words: Ducts, Sound generation, Fundamental mode

This article describes a one-dimensional, linearized, analysis of fundamental mode sound generation and propagation in rigid-walled flow ducts with axial temperature variation. An acoustic wave equation, including damping effects and volume sources, is derived and its solution (in the absence of sources) by a numerical technique and an approximate analytical method is discussed. The "forced" wave equation in then solved (the existence of an oscillating solution to the "unforced" equation being assumed) for sound generation by a sidebranch volume source in an infinite duct, and the results are applied to a duct of finite length. Reasonably good agreement is obtained between measurements and predictions of the sound pressure field in a flow duct, away from source region.

FRAMES, ARCHES

78-1304

Vibrations of Frames with Inclined Members

C.H. Chang

Dept. of Aerospace Engrg., Mech. Engrg. and Engrg. Mechanics, The Univ. of Alabama, University, AL, 35486, J. Sound Vib., 56 (2), pp 201-214 (Jan 22, 1978) 14 figs, 12 refs

Key Words: Frames, Axial vibration, Flexural vibration

A formulation for the vibrations of plane frames and trusses with inclined members including both axial and transverse vibrations is presented. The vibrations of two- and three-bar frames with various end conditions are studied. With the

slenderness ratio as a parameter, the frequency spectra with respect to the angle of inclination, α, of the side bars are depicted along with some typical normal modes.

LINKAGES

78-1305

Research on Dynamics of Four-Bar Linkage with Clearances at Turning Pairs (1st Report. General Theory Using Continuous Contact Model)

T. Furuhashi, N. Morita, and M. Matsuura
Faculty of Engrg., Shizuoka Univ., Hamamatsu, Japan, Bull. JSME, 21 (153), pp 518-523 (Mar 1978) 3 figs, 9 refs

Key Words: Four bar mechanisms, Clearance effects

This report describes the general theory of dynamics of four-bar linkage with clearances at all turning pairs, using a continuous contact model, based on the assumptions that the pin is always in contact with the socket in each pair. Dynamic motion of the linkage is analytically treated, and four coupled differential equations for the contact angles and one differential equation for the input torque are presented. According to the present theory, the forces acting at the joints are derived.

MEMBRANES, FILMS, AND WEBS

(Also see No. 1331)

78-1306

The Sound of a Suddenly Tensioned Membrane

A. Dowling
Dept. of Engrg., Univ. of Cambridge, Cambridge CB2 1PZ, UK, J. Sound Vib., 57 (2), pp 281-298 (Mar 22, 1978) 7 figs, 9 refs

Key Words: Noise generation, Membranes, Flexural vibration, Supersonic frequencies, Rotary presses

The sound produced by suddenly tugging one end of an elastic sheet is investigated. The elastic equations of motion are solved within the membrane in the limit where fluid loading may be neglected. It is found that if the membrane is paper a tension wave travels supersonically through the sheet.

PIPES AND TUBES

(Also see No. 1321)

78-1307

Acoustic Resonances in Passages Containing Banks of Heat Exchanger Tubes

R. Parker
Dept. of Mech. Engrg., Univ. College of Swansea, Singleton Park, Swansea SA2 8PP, Wales, J. Sound Vib., 57 (2), pp 245-260 (Mar 22, 1978) 4 figs, 2 tables, 4 refs

Key Words: Acoustic resonance, Tubes, Heat exchangers, Ducts

It is shown experimentally that the presence of the tubes in a heat exchanger reduces the effective speed of sound in planes normal to the axes of the tubes. The effective speeds are used to analyze the possible resonant acoustic modes of a *rectangular* duct containing a tube bank filling a section in the center of the duct. Experimental results confirm the modes and the predicted frequencies.

78-1308

Theoretical Studies of Internal Flow-Induced Instabilities of Cantilever Pipes

L.K. Shayo and C.H. Ellen
Dept. of Mathematics, Imperial College of Science and Tech., London SW7 2BZ, UK, J. Sound Vib., 56 (4), pp 463-474 (Feb 22, 1978) 2 figs, 1 table, 11 refs

Key Words: Shells, Cantilever beams, Pipes (tubes), Fluid-induced excitation

A theoretical analysis is made of the stability of a circular cross-section cantilever pipe containing an incompressible, inviscid fluid flowing uniformly and steadily in the axial direction. Beam and shell mode instabilities are examined. The study is based on the idea of obtaining a simple approximation for the fluid pressure and determining the importance of the downstream fluid behavior.

PLATES AND SHELLS

(Also see Nos. 1321, 1329)

78-1309

Transverse Vibrations of Viscoelastic Shallow Shells

J. Mazumdar and D. Bucco
Dept. of Appl. Mathematics, The Univ. of Adelaide, Adelaide, South Australia 5001, J. Sound Vib., 57 (3), pp 323-331 (Apr 8, 1978) 3 figs, 14 refs

Key Words: Shells, Flexural vibrations, Viscoelastic properties

A method for the time history of motion of shallow shells of viscoelastic material under arbitrary time-dependent transverse load is presented. The method is based upon the concept of iso-amplitude contour lines on the surface of the shell. It is shown that the time behavior can be found by using the frequency of free vibration of the associated elastic shallow shell. As an illustration of the technique, the problem of a shallow dome upon an elliptic base is discussed, all details of which are explained by graphs.

78-1310

Natural Frequencies of Cylindrical Shells and Panels in Vacuum and in a Fluid

M.K. Au-Yang

Nuclear Power Generation Div., Babcock & Wilcox, Lynchburg, VA 24505, J. Sound Vib., 57 (3), pp 341-355 (Apr 8, 1978) 2 figs, 5 tables, 10 refs

Key Words: Cylindrical shells, Panels, Natural frequencies

A unified formula for estimating the natural frequencies of circular cylindrical shells and panels in vacuum as well as in a fluid is presented. Boundary conditions considered include both simply supported and clamped. In the latter case, tables of constants are included to facilitate application of the formula. Extension of the method to estimate the frequencies of a system of cylindrical shells coupled by fluid gaps is also discussed. The methodology is particularly suitable for digital computer implementation.

78-1311

Dynamic Instability in Cylindrical Shells

H.R. Radwan and J. Genin

School of Mech. Engrg., Purdue Univ., West Lafayette, IN 47907, J. Sound Vib., 56 (3), pp 373-382 (Feb 8, 1978) 8 figs, 9 refs

Key Words: Cylindrical shells, Harmonic excitation

The stability of the steady state response of simply supported circular cylinders subjected to harmonic excitation is investigated by using variational equations reduced from "exact" non-linear modal equations. The inertia of the unperturbed vibration motion is included as well as the non-linearities in the steady state resonant response. The existence of a new mechanism of parametric excitation is predicted and the conditions by which it develops are discussed. Unstable regions are established on frequency response plots for different shell geometries. Numerical integration results for unstable conditions indicate considerable overloading of the structure and underline the practical significance of this instability mechanism.

78-1312

Studies on Vibration of Some Rib-Stiffened Cantilever Plates

M.N. Bapu Rao, P. Guruswamy, M.V. Rao, and S. Pavithran

Structural Sciences Div., National Aeronautical Lab., Bangalore-560017, India, J. Sound Vib., 57 (3), pp 389-402 (Apr 8, 1978) 13 figs, 6 tables, 6 refs

Key Words: Cantilever plates, Stiffened plates, Resonant frequencies, Mode shapes

An experimental study was carried out to determine the resonant mode shapes and frequencies of some rib-stiffened skew cantilever plates by holographic interferometry. The influences of varying the sweep back angle, the rib stiffness and the aspect ratio, and the effect of varying the boundary conditions at the root chord, on the frequencies and mode shapes were also investigated. Results of the above investigation and also those of a comparative study with the finite element solution obtained for some of the cases studied are presented and discussed.

78-1313

On the Non-Linear Vibrations of Rectangular Plates

G. Prathap and T.K. Varadan

Dept. of Aeronautics, Indian Inst. of Tech., Madras 600036, India, J. Sound Vib., 56 (4), pp 521-530 (Feb 22, 1978) 3 figs, 1 table, 22 refs

Key Words: Rectangular plates, Nonlinear response, Mode shapes

A solution, based on a one-term mode shape, for the large amplitude vibrations of a rectangular orthotropic plate, simply supported on all edges or clamped on all edges for movable and immovable in-plane conditions, is found by using an averaging technique that helps to satisfy the in-plane boundary conditions. This averaging technique for satisfying the immovable in-plane conditions can be used to resolve many anisotropic and skew plate problems where otherwise, when a stress function is used, the integration of the u and v equations becomes difficult, if not impossible. The results obtained herein are compared with those available in the literature for the isotropic case.

78-1314

On the Effect of Different Edge Flexibility Coefficients on Transverse Vibrations of Thin, Rectan-

gular Plates

P.A.A. Laura, L.E. Luisoni, and G. Ficcadenti
Inst. of Appl. Mechanics, 8111 Base Naval Puerto Belgrano, Argentina, J. Sound Vib., 57 (3), pp 333-340 (Apr 8, 1978) 6 figs, 3 tables, 8 refs

Key Words: Rectangular plates, Flexural vibrations

To solve problems of transverse vibration of thin, rectangular plates with different edge flexibility coefficients polynomial co-ordinate functions are used which identically satisfy the boundary conditions. It is shown that by a proper combination of the polynomials several modes of vibrations can be analyzed with a minimum amount of labor. A variational formulation is used to generate the frequency equation.

78-1315

Analysis of Vibration of Clamped Square Plates by the Rayleigh-Ritz Method with Asymptotic Solutions From a Modified Bolotin Method

K. Vijayakumar and G.K. Ramaiah
Dept. of Aeronautical Engrg., Indian Inst. of Science, Bangalore 560012, India, J. Sound Vib., 56 (1), pp 127-135 (Jan 8, 1978) 2 tables, 25 refs

Key Words: Plates, Flexural vibration, Rayleigh-Ritz method, Bolotin method

Estimates of flexural frequencies of clamped square plates are initially obtained by the modified Bolotin's method. The mode shapes in "each direction" are then determined and the product functions of these mode shapes are used as admissible functions in the Rayleigh-Ritz method. The data for the first twenty eigenvalues in each of the three (four) symmetric groups obtained by the Bolotin, Rayleigh, and Rayleigh-Ritz methods are reported here.

78-1316

Estimation of Fundamental Frequency of Non-Circular Plates with Free, Circular Cutouts

F.E. Eastep and F.G. Hemmig
Dept. of Mech. and Engrg. Systems, Air Force Inst. of Tech., Wright-Patterson AFB, OH 45433, J. Sound Vib., 56 (2), pp 155-165 (Jan 22, 1978) 6 figs, 15 refs

Key Words: Plates, Hole-containing media, Fundamental frequency

A method of obtaining approximate fundamental frequencies of slightly non-circular plates with free circular cutouts is developed. An approximate expression for the radius of each bounding curve is written as a truncated Fourier series. The support conditions, which are written in terms of a perturbation series of the modes of a circular annulus, are satisfied on the approximate boundaries. The approximate characteristic equation (either first or second-order approximations) is obtained from satisfaction of the support conditions and the fundamental frequency determined as the first root to this characteristic equation. Approximate frequencies of the fundamental mode of a clamped elliptical plate, square plate with a circular cutout and an eccentric annulus are determined to demonstrate the second-order approximation. In addition, the first-order approximation to the fundamental mode of an eccentric annulus is obtained.

78-1317

Free Vibration Analysis of the Completely Free Rectangular Plate by the Method of Superposition

D.J. Gorman
Dept. of Mech. Engrg., Univ. of Ottawa, Ottawa, Canada, J. Sound Vib., 57 (3), pp 437-447 (Apr 8, 1978) 9 figs, 4 tables, 4 refs

Key Words: Rectangular plates, Free vibration, Method of superposition

In a new approach to free vibration analysis of the completely free rectangular plate by using the method of superposition, it is shown that solutions which satisfy identically the differential equation and which satisfy the boundary conditions with any desired degree of accuracy are obtained. Eigenvalues of four digit accuracy are provided for a wide range of plate aspect ratios and modal shapes. Exact delineation is made between the three families of modes which are characteristic of this plate vibration problem. Accurate modal shapes are provided for the response of completely free square plates.

78-1318

Surface Response Due to Harmonic Vibration of a Rigid Disc on an Elastic Half-Space

A. Karbassioun and J.D. Richardson
School of Engrg. and Appl. Sciences, Univ. of Sussex, Brighton BN1 9QT, UK, J. Sound Vib., 56 (3), pp 363-372 (Feb 8, 1978) 1 fig, 5 tables, 13 refs

Key Words: Discs, Elastic properties, Half-space, Harmonic excitation

The harmonic vibration of a rigid disc on an elastic half-space is considered. An exact analysis is used to calculate the surface response at various distances from the disc and over a wide range of frequency. Detailed results are given for each of the four modes of vibration, and comparison is made with existing work. In particular it is noted that the results for

the horizontal translation mode are the only accurate results at present available, and that the existing results for the torsion mode, computed from the exact theory of Reissner and Sagoci, are in error. This latter point is confirmed by a recomputation of Reissner and Sagoci's solutions with excellent agreement obtained between these results and those of the present work.

RINGS

78-1319

Measurement of Dynamic Cutting Force Coefficients

B.S. Goel

Ph.D. Thesis, McMaster Univ. (Canada) (1977)

Key Words: Metal working, Cutting, Dynamic response

The dynamic behavior of metal cutting process is investigated by measuring the various components of dynamic cutting force. For the complete description of dynamics of metal cutting it is necessary to give eight components belonging to the resultant dynamic cutting force in an orthogonal cutting process. An experimental technique termed as the Double Modulation Method has been developed to measure the above eight coefficients for various cutting conditions of speed, feed, frequency, tool wear and work piece materials. The method is based on the Fast Fourier Transform of the measured signals of dynamic cutting forces and tool work piece relative displacement.

SPRINGS

78-1320

Nonlinear Wave Propagation in Helical Springs by the Method of Characteristics and Finite Element Method

S.K. Sinha

Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 131 pp (1977)

UM 7804159

Key Words: Helical springs, Impact response (mechanical), Nonlinear response, Shock wave propagation, Method of characteristics, Finite element technique

The problem considered is that of a helical spring which is fixed at one end and impacted at the other end with sufficient velocity so as to cause contact between the coils. The problem has been solved by two different methods viz., the method of characteristics and the finite element method.

STRUCTURAL

78-1321

Eight Node Elasticity Finite Element for Stress Vibration and Buckling Problems

M.H. Imam

Ph.D. Thesis, Univ. of Southern California (1977)

Avail: Micrographics Dept., Doheny Library, USC, Los Angeles, CA 90007

Key Words: Shells, Beams, Plates, Finite element technique, Elasticity theory

A plane stress, plane strain and body of revolution eight node finite element was developed to determine the stress, vibration and the buckling of beam, circular plates, and thick and thin cylindrical, conical and hyperboloidal shells, and other complex structures. A computer program was written to obtain results with this element. Numerical results obtained were in excellent agreement with the classical results. Beam vibration problems which consider the effects of a bending moment were solved using the developed elasticity theory. This effect cannot be considered with simple beam theory.

78-1322

Contribution of a Floor System to the Dynamic Characteristics of R/C Buildings

L.J. Edgar

Ph.D. Thesis, Univ. of California, Berkeley, 290 pp (1976)

UM 7715670

Key Words: Stiffness methods, Matrix methods, Floors, Multistory buildings

A practicable and sufficiently accurate stiffness matrix method for estimating the contribution of a floor system to the overall elastic stiffness of moment-resisting space frames is developed. The floor system considered consisted of a two-way reinforced concrete slab supported by beams between the columns.

78-1323

Effect of Beam Strength and Stiffness on Dynamic Behavior of Reinforced Concrete Coupled Walls

J.M. Lybas

Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 593 pp (1977)

UM 7804079

Key Words: Walls, Beams, Reinforced concrete, Seismic response, Hysteretic damping

Earthquake simulation studies on reinforced concrete walls are described. The earthquake loading was of a magnitude sufficient to cause yielding of the test structures. Horizontal acceleration and displacements of the test structures at several levels were measured. A similar test structure was subjected to slowly applied cyclic lateral loading, producing yielding in both directions. Lateral load and deflection in the form of load-deflection hysteresis relations were obtained. Variables in the experimental program were strength and stiffness of the connecting beams. In addition, hysteresis relations for the structure under both types of loading were investigated analytically.

78-1324

Dynamic Buckling of Axisymmetric Spherical Caps with Initial Imperfections

R. Kao and N. Perrone

School of Engrg. and Appl. Science, George Washington Univ., Washington D.C., 41 pp (Dec 1977)

AD-A048 844/5GA

Key Words: Caps (supports), Initial imperfection effects, Dynamic buckling

Dynamic buckling loads are obtained for axisymmetric spherical caps with initial imperfections. Two types of loading are considered, namely, step loading of infinite duration and right triangular pulse.

SYSTEMS

NOISE REDUCTION

(Also see No. 1352)

78-1325

Three Methods for Predicting the Insertion Loss of Close-Fitting Acoustical Enclosures

L.W. Tweed and D.R. Tree

Fiat-Allis, 3000 S. 6th St., Springfield, IL 62710, Noise Control Engr., 10 (2), pp 74-79 (Mar/Apr 1978) 5 figs, 9 refs

Key Words: Enclosures, Sound transmission loss, Noise reduction

The theories of Jackson, Ver, and Junger for the prediction of insertion loss were tested experimentally and results were compared.

AIRCRAFT

(Also see No. 1223)

78-1326

Drag Effects on Wing Flutter

A. Petre and H. Ashley

Dept. of Aeronautics and Astronautics, Stanford Univ., Stanford, CA, Rept. No. AFOSR-TR-77-0608, 11 pp (May 23, 1975)

AD-A049 373/4GA

Key Words: Aircraft wing, Flutter

Using the large-aspect-ratio, cantilever wing as a model, the question is addressed as to whether forces to drag type may have a significant influence on dynamic aeroelastic stability. The elementary example of an elastically suspended typical section airfoil with constant drag and quasisteady airloads is analyzed. Extensive flutter calculations then are carried out through numerical solution of the integral equations for a uniform wing with distributed properties in bending and torsion.

78-1327

Effects of Structural Non-Linearities on Aircraft Vibration and Flutter

E. Breitbach

AGARD, Paris, France, Rept. No. AGARD-R-665; ISBN-92-835-1270-7, 17 pp (Jan 1978)

N78-17076

Key Words: Aircraft vibration, Flutter, Nonlinear theories

The physical sources of various types of nonlinearities were examined and their influence on the different parts of the flutter clearance process was investigated. Methods which permit quantitative solutions of nonlinear aeroelastic problems were also surveyed.

78-1328

Dynamic Analysis of an In-Flight Refueling System

J. Eichler

Ben Gurion Univ. of the Negev, Israel, J. Aircraft, 15 (5), pp 311-318 (May 1978) 7 figs, 7 tables, 3 refs

Key Words: Aircraft wings, Wing stores, Storage tanks, Fuel storage

A dynamic analysis was performed on an in-flight refueling system. This system has twin refueling pods set far out on the wings. Consequently, the effects of wing vibration and vortex become important, together with the usual disturbance of vertical wind gusts. The paper presents the derivation and solution of the nonlinear partial differential equations.

BIOENGINEERING

78-1329

Axisymmetric Vibration of Human Skull-Brain System

J.C. Misra

Dept. of Mathematics, Indian Inst. of Tech., Kharagpur 721 302, India, Ing. Arch., 47 (1), pp 11-19 (1978) 10 figs, 11 refs

Key Words: Bioengineering, Head (anatomy), Spherical shells, Axisymmetric vibrations

Vibrations of the human head modeled as a prolate spheroidal shell are considered. The shell is assumed to be made of a linear viscoelastic solid containing a viscoelastic fluid representing the brain. Steady-state response of human-sized skull-brain system due to an axisymmetric load is analyzed. The effect of the eccentricity of the shell on its stiffness is found to be quite significant.

BRIDGES

78-1330

Symposium on Dynamic Behaviour of Bridges

Transport and Road Research Lab., Crowthorne, UK, Rept. No. TRRL-SUPPLEMENTARY-275, 122 pp (1977)

PB-276 671/5GA

Key Words: Bridges, Vibration damping, Wind-induced excitation

The damping of highway bridges was reviewed at the symposium. The following topics were discussed: mechanism damping; damping; damping measurements on steel and composite bridges; dynamic response of bridge superstructures; dynamic response to traffic and wind; correlation of calculated and measured dynamic behavior of bridges; design criteria and analysis for dynamic loading of footbridges; and an engineer's approach to dynamic aspects of bridge design.

78-1331

Bridge Vibration Studies

A. Shahabadi

Ph.D. Thesis, Purdue Univ., 252 pp (1977)

UM 7803282

Key Words: Bridges, Traffic-induced vibrations, Human response

The objective of this investigation was to study the vibration of highway bridges due to moving vehicles and the effect of vibrations on bridge users. In order to establish a criterion for human response to vibration, available literature on human response to vibration was reviewed. Since the primary vibration of girder bridges is in the vertical direction, the effect of vertical vibration (foot to head direction) on the human body was studied.

78-1332

Nonlinear Soil-Structure Interaction of Skew Highway Bridges

M. Chen and J. Penzien

Earthquake Engrg. Res. Center, California Univ., Richmond, CA., Rept. No. UCB/EERC-77/24, 127 pp (Aug 1977)

PB-276 176/5GA

Key Words: Interaction: soil-structure, Bridges, Seismic excitation, Mathematical models, Computer programs

Presented in this report is a study of the behavior of short, skew highway bridges interacting with their surrounding soils during strong motion earthquakes. The first part of the study defines a three-dimensional, nonlinear mathematical model for the complete bridge-soil system while the second part develops the associated computer program for carrying out time-history dynamic response analysis.

BUILDING

78-1333

Studies on the Seismic Design of Low-Rise Steel Buildings

C.J. Montgomery and W.J. Hall

Dept. of Civil Engrg., Illinois Univ. at Urbana-Champaign, IL, Rept. No. SER-442, UILU-ENG-77-

2012, NSF/RA-770318, 181 pp (July 1977)
PB-276 733/3GA

Key Words: Buildings, Earthquake resistant structures, Seismic design

The seismic analysis and earthquake resistant design of steel low-rise shear buildings, moment frame buildings, and x-braced frame buildings are studied. A number of two- and three-story buildings were designed according to the recommendations of modern building codes.

78-1334

A Study of the Apparent Change in the Foundation Response of a Nine-Story Reinforced Concrete Building

D.A. Foutch and P.C. Jennings

Bull. Seismol. Soc. Amer., 68 (1), pp 219-229 (Feb 1978) 7 figs, 8 refs

Key Words: Multistory buildings, Reinforced concrete, Earthquake damage

The purpose of this study is to examine the indication that the foundation response of the structure may have changed because of the earthquake. To determine whether the observed changes in foundation response are consistent with the change in natural period, two analytical models of the Millikan Library building were developed. Both of these models include the effects of foundation compliance and one includes the effects of shear deformations in the walls of the structure. The results of these simple analyses show the changes of mode shape and period observed between the two tests to be consistent.

78-1335

Studies on the Seismic Design of Low-Rise Steel Buildings

C.J. Montgomery

Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 180 pp (1977)
UM 7804090

Key Words: Buildings, Seismic design, Codes (standards)

This dissertation presents studies on the seismic analysis and earthquake resistant design of steel low-rise shear buildings, moment frame buildings, and X-braced frame buildings. In the first portion of the study, a number of two and three-story buildings were designed according to the recommendations of modern building codes. In addition, two simpler methods of analysis, the modal method used in conjunction with inelastic response spectra and the quasi-static building code approach modified to explicitly take inelastic behavior into account, were evaluated for use in calculating response quantities. In the last section of the dissertation, the application of the results of these studies to the practical design of low-rise steel buildings is discussed. A simplified design procedure that is in part similar to the quasi-static building code approach presently recommended by the Applied Technology Council III study is discussed.

78-1336

Seismic Shears and Overturning Moments in Buildings

R. Smilowitz

Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 147 pp (1977)
UM 7804163

Key Words: Buildings, Beams, Seismic design, Parametric response, Modal analysis

In this study a procedure is presented for determining the design distribution of story shears and overturning moments in buildings subjected to strong ground motions, with particular emphasis on tall buildings. A parameter study was conducted and modal analyses were performed to determine the influence of the following variables on the most probable response to earthquake excitation at various levels in a building. Sets of acceleration distributions and base values are presented for calculating separately story shears and overturning moments over the height of the building. Statistical comparisons of the various conditions are presented in a design format for use in the preliminary proportioning of structural members.

CONSTRUCTION

78-1337

Dynamic Behavior of a Load Lifted by a Mobile Construction-type Crane (4th Report. The Study on Boom Hoist Motion, etc.)

H. Ito, Y. Senda, and H. Fujimoto

Kobe Steel Ltd., Akashi, Japan, Bull. JSME, 21 (154), pp 600-608 (Apr 1978) 10 figs, 1 table, 5 refs

Key Words: Hoists, Cranes (hoists)

This paper deals with the behavior of a load lifted by a mobile crane during boom hoisting, and during boom hoisting and lowering which are executed at the same time. The equations of motion are given in the form of Lagrange's equation, and the solutions are obtained by Runge-Kutta-Gill method. In experiments the rope tension was measured with load cells, and displacements of the load and the boom point were measured with cameras and sound-wave.

FOUNDATIONS AND EARTH

78-1338

Normal Modes of a Laterally Heterogeneous Body: A One-Dimensional Example

R.J. Geller and S. Stein
Dept. of Geophysics, Stanford Univ., CA 94305,
Bull. Seismol. Soc. Amer., 68 (1), pp 103-116 (Feb 1978) 3 figs, 22 refs

Key Words: Normal modes, Earth models, Variational methods, Rayleigh-Ritz methods

Various methods, including first- and second-order perturbation theory and variational methods have been proposed for calculating the normal modes of a laterally heterogeneous earth. In this paper, three of these methods are tested for a simple one-dimensional example for which the exact solution is available: an initially homogeneous "string" in which the density and stiffness are increased in one half and decreased in the other by equal amounts.

78-1339

Analyze Your Engine Foundations

W.M. Kauffmann
Power, 122 (5), pp 68-71 (May 1978) 6 figs

Key Words: Engine foundations, Soils, Natural frequencies

When the disturbing force in the engine or compressor, say from primary or secondary imbalance, is at the same frequency as that of the combined foundation and soil system, serious vibration occurs. The effect of natural frequency of soil in elastic systems comprising engine foundation and supporting soil and piling is presented. The importance of designing foundations early in the planning stage is stressed, and a typical problem is illustrated. Additional problems, which might arise after the unit enters the service, are considered; among them, problems arising from soil compaction and changes in concrete foundation blocks, caused by chemical reaction and temperature.

HELICOPTERS

(See No. 1260)

HUMAN

(Also see No. 1331)

78-1340

The Prediction of Passenger Riding Comfort from Acceleration Data

C.C. Smith, D.Y. McGehee, and A.J. Healey
Dept. of Mech. Engrg., The Univ. of Texas at Austin, TX,
J. Dyn. Syst. Meas. and Control, Trans. ASME, 100 (1), pp 34-41 (Mar 1978) 5 figs, 3 tables, 5 refs

Key Words: Ride dynamics, Human response

Various methods for evaluating ride quality in automobiles are investigated by means of a field study involving two different automobiles, seventy-eight different passengers, and eighteen different roadway sections. Passenger rating panels were used to obtain subjective evaluation of the various rides, and measured vibration spectra were examined on the basis of various frequency weighting techniques to determine their ability to predict the subjective ratings. Included in the evaluation criteria considered are weighting functions derived from the ISO (International Standards Organization) Standard, the UTACV (Urban Tracked Air Cushion Vehicle) Specification, and the Absorbed Power method of Lee and Pradko. Equations are presented to predict the subjective ride rating from measured vibration spectra.

78-1341

A Review of the Effects of Vibration on Visual Acuity and Continuous Manual Control. Part I: Visual Acuity

M.J. Griffin and C.H. Lewis
Inst. of Sound and Vib. Res., Univ. of Southampton, Southampton S09 5NH, UK,
J. Sound Vib., 56 (3), pp 383-413 (Feb 8, 1978) 5 figs, 65 refs

Key Words: Vibration effects, Human response

This is the first part of a review of the effects of vibration on vision and continuous manual control. In this part experimental research into the effects on human vision of both object vibration and whole-body vibration is summarized. Knowledge of the respective effects of vibration variables (principally amplitude, frequency and direction) and visual task variables (such as illumination, size and viewing distance) is discussed in separate sections.

78-1342

A Review of the Effects of Vibration on Visual Acuity and Continuous Manual Control. Part II:

Continuous Manual Control

C.H. Lewis and M.J. Griffin
Inst. of Sound and Vib. Res., Univ. of Southampton, Southampton S09 5NH, UK, J. Sound Vib., 56 (3), pp 415-457 (Feb 8, 1978) 11 figs, 91 refs

Key Words: Vibration effects, Human response

This second, and final part of a review of the effects of vibration on human performance is concerned with continuous manual control, or tracking. As in the first part, which dealt with the effects of vibration on vision, the task and vibration variables which have been shown to affect the sensitivity of a task to vibration are discussed separately. Other sections are concerned with the measurement of tracking performance in vibration environments, general conclusions about the nature and mechanisms of the effects of vibration on tracking and the application of these conclusions in the form of predictive models. The procedures and results of most of the laboratory studies of vibration and tracking performance are separately summarized in tabular form in the Appendix as a convenient guide to the relevant literature.

78-1343

Hand-Arm Vibration. Part III: A Distributed Parameter Dynamic Model of the Human Hand-Arm System

L.A. Wood, C.W. Suggs, and C.F. Abrams, Jr.
School of Mech. and Industrial Engrg., The Univ. of New South Wales, P.O. Box 1, Kensington, N.S.W. 2033, Australia, J. Sound Vib., 57 (2), pp 157-169 (Mar 22, 1978) 10 figs, 14 refs

Key Words: Human hand, Vibration response, Mathematical models, Beams

An anatomically analogous distributed parameter dynamic model of the human arm is proposed and quantitatively validated. Distributed mass and stiffness parameters have been obtained by representing each long bone of the arm as a flexural beam. A distributed damping parameter was introduced by allowing the beam stiffness to be a complex quantity. Hand properties were modeled as a lumped parameter damped spring-mass system. Mechanical driving point impedance techniques were used to verify the model.

ISOLATION

(See No. 1252)

METAL WORKING AND FORMING

78-1344

Dynamic Characteristics of the Hydraulic Feed System of Machine Tools (1st Report: Amplitude and Period of Stick-slip Oscillation)

T. Teshima and Y. Komura
Faculty of Engrg., Fukui Univ., Bunkyo-3, Fukui, Japan, Bull. JSME, 21 (153), pp 463-470 (Mar 1978) 16 figs, 12 refs

Key Words: Stick-slip response, Machine tools

The phenomenon of stick-slip oscillations of the feed drives of machine tools is an important problem in the designing of a hydraulic feed system because of its low stiffness. The basic equations of the slider motion on a machine tool guideway when some amount of air is included in the hydraulic system are set up, and solved numerically by Runge-Kutta-Gill method. The results obtained are compared to experiments.

PACKAGE

78-1345

Evaluation of Cushion Dynamic Properties by Impedance Measurements

E.M. Nassar
Arab Organization for Industrialization, Cairo, Egypt, J. Test Eval., 6 (3), pp 231-236 (May 1978) 8 figs, 3 tables, 6 refs

Key Words: Packaging materials, Stiffness coefficients, Damping coefficients, Mechanical impedance

A method is proposed for the evaluation of cushions in dynamic environments. With the mechanical impedance technique the cushion properties are determined in terms of equivalent distributions of stiffness, damping, and mass parameters. Test results on a specific material show that these parameters may be considered of constant magnitude within limited ranges of frequencies and input levels. The equivalent cushion parameters are presented in dimensionless form as functions of the geometry and the input levels.

PRESSURE VESSELS

78-1346

Free Vibrations of Skirt Supported Pressure Vessels – An Engineering Application of Timoshenko Beam Theory

M. Levinson and M. El Menoufy

Dept. of Civil Engrg. and Engrg. Mech., McMaster Univ., Hamilton, Ontario, Canada L8S 4L7, J. Sound Vib., 57 (3), pp 413-424 (Apr 8, 1978) 7 figs, 2 tables, 8 refs

Key Words: Pressure vessels, Timoshenko theory, Free vibration

Timoshenko beam theory is applied to the study of the free vibrations of skirt supported pressure vessels in this paper; such systems are used in the process and power generation industries as well as aboard nuclear powered vessels.

PUMPS, TURBINES, FANS, COMPRESSORS

(Also see No. 1229)

78-1347

Noise Generated by Low Pressure Axial Flow Fans. III: Effects of Rotational Frequency, Blade Thickness and Outer Blade Profile

T. Fukano, Y. Kodama, and Y. Takamatsu

Faculty of Engrg. 36, Kyushu Univ., Fukuoka, Japan, J. Sound Vib., 56 (2), pp 261-277 (Jan 22, 1978) 14 figs, 3 tables, 7 refs

Key Words: Fans, Noise generation

Experimental results for the effects of fan rotational frequency and blade thickness at the trailing edge are described and these results are compared with the theory. It is shown that the outer profile of the blade has considerable effects on both noise and aerodynamic characteristics of fans: that is, impellers with blades swept forward are much superior to those with blades swept backward.

78-1348

Fan Availability Threatened by Three Primary Phenomena

The 1978 Electric Utility Generation Planbook, Edited by Power Magazine, pp 137-140 (1978) 12 figs, 4 refs

Key Words: Fans, Failure analysis

The most common reasons for unscheduled outages caused by fans are bearing failure, erosion, and vibration. After a brief discussion of each item, suggestions for fan operation and maintenance are offered. Most comments are directed toward the severest fan duty, that of gas recirculation and induced-draft applications, but forced-draft and primary-air fans are also considered.

78-1349

Scale Model Performance Testing to Assess the Effect of a Foundation Transverse Rocking Vibration Mode on Centrifugal Industrial Fan Shafts

G.R. Tomlinson

Sturtevant Engrg. Products Ltd., Denton, Manchester, UK, Scaling for Performance Prediction in Rotordynamic Machines, Papers presented at the Conf. held at the Univ. of Stirling, 1977, Sept 6-8, London: Institution of Mechanical Engineers, 1977, pp 41-44, 7 refs

Key Words: Fans, Model testing, Vibration tests

Tests have been carried out on a scale model, representing the essential features of a centrifugal fan system and a low tuned concrete foundation. The test results show the effect of reducing the fan shaft natural frequency until it approaches the concrete foundation rocking mode natural frequency. A factor of safety is derived which should prevent rough running of such a system due to any interaction between the foundation and shaft amplitudes of vibration resulting from the closeness of their respective natural frequencies. A theoretical model is also described which supports the experimental results.

78-1350

Flow Excited Vibrations in High-Pressure Turbines (Steam Whirl)

E. Pollman, H. Schwerdtfeger, and H. Termuehlen

Kraftwerk Union AG, Muelheim (Ruhr), West Germany, J. Engr. Power, Trans. ASME, 100 (2), pp 219-228 (Apr 1978) 13 figs, 2 tables, 32 refs

Key Words: Steam turbines, Fluid-induced excitation

The following excitation mechanisms of nonsynchronous vibrations of high speed turbine generators were investigated: the gas bearing effect, Lomakin effect, Alford effect, spiral flow effect, load dependent excitation (steam whirl), material friction, and others.

RAIL

78-1351

Power Spectral Density for Constrained Long Wave-

length Guideway Irregularities
M.B. Krishna and D. Hullender
Rockwool Industries, Inc., Belton, TX, J. Dyn. Syst. Meas. and Control, Trans. ASME, 100 (1), pp 18-23 (Mar 1978) 9 figs, 10 refs

Key Words: Guideways, Power spectra, Spectral energy distribution

An equation for the power spectral density (PSD) of guideway irregularities that have been constrained to lie within a designated band is formulated. The equation enables guideway designers to control the upper bound on the long wavelength portion of the roughness PSD. The paper also provides insight into the accuracy of two quasilinear modeling techniques for nonlinearities with random inputs.

REACTORS

(Also see No. 1259)

78-1352
Control of Steam Venting Noise in Power Plants
J.K. Floyd
Pulsco Div., American Air Filter Co., Louisville, KY, J. Engr. Power, Trans. ASME, 100 (2), pp 369-373 (Apr 1978) 10 figs, 2 tables, 7 refs

Key Words: Nuclear power plants, Noise reduction

Steam venting to atmosphere from piping system pressures as high as 2500 psig, as may occur during safety valve and power relief valve operation or during initial steam piping clean up, is one of the most intense sources of noise emitted by fossil and nuclear power plants. This paper discusses characteristics of sonic and turbulent vent noise.

ROAD

(Also see Nos. 1224, 1240, 1340)

78-1353
Finite Element Methods Reduce Interior Noise
Automotive Engineering (SAE), 86 (5), pp 32-37 (May 1978) 5 figs

Key Words: Automobiles, Vibration reduction, Finite element method

Finite element methods are applied to evaluate the effect of the lower frequency structural modes and the lower frequency cavity acoustic modes on noise in the automobile passenger compartment.

78-1354
The Application of Isotropy in Road Surface Modelling
K.M.A. Kamash and J.D. Robson
Dept. of Mech. Engrg., Univ. of Glasgow, Glasgow G12 8QQ, UK, J. Sound Vib., 57 (1), pp 89-100 (Mar 8, 1978) 6 figs, 8 refs

Key Words: Road roughness, Surface roughness, Isotropy, Mathematical models

Road surface description forms the basis of vehicle response prediction, but in most cases precise description of a particular road is of less value than a description representative of a class of roads. In these circumstances an analytical road surface model has special advantages. In modeling a road surface -- rather than a single road profile -- the hypothesis of isotropy is shown to provide a useful basis, and the paper shows how a particular profile spectral density, together with the assumption of isotropy, can be used to define an effective surface model. Coherence functions derived from the proposed model are validated by comparison with coherencies based on measurement.

ROTORS

(Also see No. 1257)

78-1355
Calculation of Flexural Vibrations of Printing Mechanisms in Rotating Cylindrical Printing Machines (Berechnung von Biegeschwingungen in Druckwerken von Rollenrotationsmaschinen)
D. Müller
Maschinenbautechnik, 26 (11), pp 505-508 (Nov 1977) 3 figs, 6 refs
(In German)

Key Words: Flexural vibrations, Cylinders, Printing

A linear continuous vibration model for the determination of dynamic response of a cylindrical printing mechanism is described. The conservative boundary value problem is approximated using Galerkin method.

78-1356
The Aperiodic Behaviour of a Rigid Shaft in Short Journal Bearings

A.G. Holmes, C.M.M. Ettles, and I.W. Mayes
Mech. Engrg. Dept., Imperial College, London, UK, Intl. J. Numer. Methods Engr., 12 (4), pp 695-702 (1978) 5 figs, 5 refs

Key Words: Shafts, Rotor-bearing systems, Periodic response, Boundary value problems

A study is presented of the symmetrical steady-state motion of a rigid shaft supported by two 'short' (Ocvirk) journal bearings. The equations of motion for a balanced or unbalanced shaft were solved using numerical 'initial value problem' techniques. Frequency analysis, which was used to determine the components of the steady-state motion, confirmed that, for most conditions, the motion was asymptotically periodic comprising a small number of components - principally at synchronous and half synchronous frequency. However, a region of the operating space was found, in which the motion was complex and did not settle to a limit cycle. An estimate of the extent of this region is given and the suspected cause investigated.

78-1357

Bearingless Tail Rotor Loads and Stability

W.T. Edwards and W. Miao
Boeing Vertol Co., Philadelphia, PA, Rept. No. D210-11025-1, USAAMRDL-TR-76-16, 289 pp (Nov 1977)
AD-A049 579/6GA

Key Words: Rotors, Wind tunnel tests, Aerodynamic stability

Four wind tunnel model tests were conducted on a model flex-strap bearingless tail rotor was studied for aeroelastic stability characteristics and loads. In all, 12 individual rotor parameters were investigated to determine their effect on aeroelastic stability.

78-1358

Torquewhirl -- A Theory to Explain Nonsynchronous Whirling Failures of Rotors with High-Load Torque

J.M. Vance
Univ. of Florida, Gainesville, FL, J. Engr. Power, Trans. ASME, 100 (2), pp 235-240 (Apr 1978) 7 figs, 10 refs

Key Words: Rotors, Shafts, Whirling

Numerous unexplained failures of rotating machinery by nonsynchronous shaft whirling point to a possible driving mechanism or source of energy not identified by previously existing theory. A majority of these failures have been in machines characterized by overhung disks (or disks located close to one end of a bearing span) and/or high power and load torque. This paper gives exact solutions to the nonlinear differential equations of motion for a rotor having both of these characteristics and shows that high ratios of driving torque to damping can produce nonsynchronous whirling with destructively large amplitudes. Solutions are given for two cases: viscous load torque and damping, and load torque and damping proportional to the second power of velocity (aerodynamic case). Criteria are given for avoiding the torquewhirl condition.

SELF-EXCITED

78-1359

Self-Induced Vibrations by Thermal Stress

H. Madarame
Faculty of Tenrg., Univ. of Tokyo, Hongo Bunkyo-ku, Tokyo, Japan, Bull. JSME, 21 (153), pp 412-423 (Mar 1978) 33 figs, 8 refs

Key Words: Wires, Beams, Thermal excitation, Self-excited vibrations

A metal beam heated by the passage of an electric current may begin to vibrate laterally under certain conditions. A horizontal wire heated by the current may also begin to vibrate vertically. When a beam moves in one direction, the front surface is cooled more than the back surface. In high frequency region, a phase lag is generated and the back surface is cooled more. Hence, in lower frequency region, the fundamental mode of cantilever at which the front part is shrinking is induced. The temperature of a wire, vibrating with high frequency, becomes low when it moves upwards. Then the reduction of static deflection occurs, the direction of which is equal to that of the motion of the vibrating wire. Therefore, with energy gained, a vibration can be induced.

SHIP

78-1360

Heave Motion of Air Cushion Vehicles

M.R. Swift and D. Lebel
Univ. of New Hampshire, Durham, NH, J. Hydronautics, 12 (2), pp 85-87 (Apr 1978) 1 fig, 8 refs

Key Words: Ground effect machines, Heaving, Equations of motion

In this paper, the heave motion of air cushion vehicles alone is considered, which reduces the complexity of the equation of motion and the conservation of air mass expression. These relations are used to solve for the heave coordinate in terms of the wave parameters and the craft speed and design specifications. The theory is then discussed in terms of the heave motion frequency response and is compared with data obtained by experiment using a scale model in a towing tank.

78-1361

Seakeeping Dynamics of a Single Cushion, Peripheral Cell-Stabilized Air Cushion Vehicle

R. Carrier, A.H. Magnuson, and M.R. Swift
Univ. of New Hampshire, Durham, NH, J. Hydronautics, 12 (2), pp 49-54 (Apr 1978) 9 figs, 1 table, 12 refs

Key Words: Ground effect machines, Dynamic response

A study of air cushion vehicle (ACV) motion in waves is presented for a single cushion ACV having a cellular, peripheral cell-type skirt system. The craft is considered to be traveling at constant speed while encountering regular waves of arbitrary heading. The dynamic equations for pitch, heave, and roll motions are derived using the cushion and cell air flow equations. These equations are solved numerically using a digital computer. The results are shown as frequency response curves giving steady-state motion response amplitudes as a function of encounter frequency or wavelength for fixed craft speed and wave steepness.

78-1362

A Note on Structural Damping of Ship Hulls

R.E.D. Bishop and W.G. Price
Dept. of Mech. Engrg., Univ. College London, London WC1E 7JE, UK, J. Sound Vib., 56 (4), pp 495-499 (Feb 22, 1978) 1 fig, 2 tables, 4 refs

Key Words: Ship hulls, Damping

Existing information on the structural damping of ships is far from satisfactory. It cannot be calculated and it can only be measured in the presence of hydrodynamic damping, whose nature and magnitude are also somewhat obscure.

TRANSMISSIONS

78-1363

Transmission Design with Finite Element Analysis. Part 2

R.W. Howells
Power Transm. Des., 20 (5), pp 46-49 (May 1978) 7 figs, 4 refs

Key Words: Power transmission systems, Finite element technique, Helicopter rotors, Vibration control

Finite element analysis is fast becoming a regular technique for drive designers. A transmission design tool using finite element methods is presented. A computer model for a rotor transmission is developed and is applied to optimize transmission design. The current effort is concentrated in two areas -- to minimize overall vibration and noise levels and to optimize the housing structural design.

TURBOMACHINERY

(See No. 1284)

AUTHOR INDEX

TECHNICAL NOTES

A.K. Mittal
Note on Weighted Mean Square Linearization Method in Non-Linear Oscillation Problems
J. Sound Vib., 57 (3), pp 464-467 (Apr 8, 1978)

B.K. Shivamoggi
Uniformly Valid Mach Number Expansion of the Navier-Stokes Equations and Mathematical Formalization of Lighthill's Theory of Aerodynamically Generated Sound: Extension to Non-Adiabatic Cases
J. Sound Vib., 57 (3), pp 453-456 (Apr 8, 1978)
4 refs

B.K. Shivamoggi
Propagation of Weakly Non-Linear Non-Dispersive Acoustic Waves
J. Sound Vib., 57 (4), pp 609-611 (Apr 22, 1978)
2 refs

A. Bokor
Transient Response of a Two-Section with a Time Dependent Boundary Condition
J. Sound Vib., 56 (4), pp 586-592 (Feb 22, 1978)
1 fig, 2 refs

J.I. Dunlop
Impedance of Closed Front Fibre Masses - Amplitude Dependent Damping
J. Sound Vib., 58 (1), pp 152-153 (1978) 1 fig, 1 table, 2 refs

R. Singh and W. Soedel
Assessment of Fluid-Induced Damping in Refrigeration Machinery Manifolds
J. Sound Vib., 57 (3), pp 449-452 (Apr 8, 1978)
2 figs, 1 table, 6 refs

C. Massalas and K. Soldatos
Free Vibrations of a Beam Subjected to Elastic Constraints
J. Sound Vib., 57 (4), pp 607-608 (Apr 22, 1978)
2 refs

E.C. Ting
On the Natural Frequencies of Continuous Beam Structures
J. Sound Vib., 57 (3), pp 457-459 (Apr 8, 1978)
6 refs

M. Dede, R.A. Scott, and J. Anderson
Equations for Non-Planar, Non-Linear Motions of Buckled Beams
J. Sound Vib., 58 (1), pp 149-151 (1978)

K.S. Aravamudan
Reduction in Response of an Infinite Beam to a Periodic Support System
J. Sound Vib., 58 (1), pp 143-145 (1978)

M. Dede, R.A. Scott, and W.J. Anderson
A Note on the Damping of Large Amplitude Beam Vibrations
J. Sound Vib., 56 (4), pp 571-574 (Feb 22, 1978)
2 figs, 4 refs

G. Venkateswara Rao and K. Kanaka Raju
Large Amplitude Vibrations of Beams with Elastically Restrained Ends
J. Sound Vib., 57 (2), pp 302-304 (Mar 22, 1978)
2 tables, 7 refs

D. Narayana Dutt and B.S. Ramakrisha
Vibration Control of Stretched Strings by an External Distributed Force
J. Sound Vib., 57 (4), pp 603-606 (Apr 22, 1978)
1 fig, 4 refs

L.R. Koval
On Sound Transmission into a Heavily-Damped Cylinder
J. Sound Vib., 57 (1), pp 155-156 (Mar 8, 1978)
2 figs, 1 ref

J.H.B. Poole and H.G. Leventhall
Active Attenuation of Noise in Ducts
J. Sound Vib., 57 (2), pp 308-309 (Mar 22, 1978)
2 figs, 2 refs

C. Massalas and K. Soldatos
Comments on Free Vibration of a Circular Cylindrical Panel
J. Sound Vib., 58 (1), pp 146-148 (1978) 1 table, 6 refs

L.K. Shayo and C.H. Ellen
A Simple Approximate Expression for the Natural Frequencies of Circular Cross Section Cantilever Pipes
J. Sound Vib., 56 (4), pp 582-585 (Feb 22, 1978)
1 table, 6 refs

CALENDAR

OCTOBER 1978

3-5 **Army Symposium on Solid Mechanics** [AMMRC] Cape Cod, MA *(AMMRC. Attn: DRXMRT, Watertown, MA 02172 - Tel. (617) 923-3253)*

8-11 **Diesel and Gas Engine Power Conference and Exhibit,** [ASME] Houston, TX *(ASME Hq.)*

8-11 **Petroleum Mechanical Engineering Conference,** [ASME] Houston, TX *(ASME Hq.)*

17-19 **49th Shock and Vibration Symposium,** [U.S. Naval Research Lab.] Washington, D.C. *(H.C. Pusey, Director, The Shock and Vibration Info. Ctr., Code 8404, Naval Res. Lab., Washington, D.C. 20375 - Tel. (202) 767-3306)*

17-19 **Joint Lubrication Conference,** [ASME] Minneapolis, MN *(ASME Hq.)*

24-26 **Stapp Car Crash Conference** [SAE] University of Michigan, Ann Arbor, MI *(SAE Meetings Dept., 400 Commonwealth Dr., Warrendale, PA 15096 - Tel. (412) 776-4841)*

NOVEMBER 1978

26-30 **Acoustical Society of America** [ASA] Salt Lake City, UT *(ASA Hq.)*

26-Dec 1 **Acoustical Society of America, Fall Meeting,** [ASA] Honolulu, Hawaii *(ASA Hq.)*

27-30 **Aerospace Meeting,** [SAE] Town & Country, San Diego, CA *(SAE Meetings Dept., 400 Commonwealth Dr., Warrendale, PA 15096 - Tel. (412) 776-4841)*

DECEMBER 1978

4-6 **15th Annual Meeting of the Society of Engineering Science, Inc.,** [SES] Gainesville, FL *(Prof. R.L. Sierakowski, Div. of Continuing Education, Univ. of Florida, 2012 W. University Ave., Gainesville, FL 32603)*

10-15 **Winter Annual Meeting,** [ASME] San Francisco, CA *(ASME Hq.)*

11-14 **Truck Meeting,** [SAE] Hyatt Regency, Dearborn, MI *(SAE Meetings Dept., 400 Commonwealth Dr., Warrendale, PA 15096 - Tel. (412) 776-4841)*

FEBRUARY 1979

26-Mar 2 **Congress & Exposition,** [SAE] Cobo Hall, Detroit, MI *(SAE Meetings Dept., 400 Commonwealth Dr., Warrendale, PA 15096 - Tel. (412) 776-4841)*

JUNE 1979

11-15 **Acoustical Society of America, Spring Meeting,** [ASA] Cambridge, MA *(ASA Hq.)*

*U.S. GOVERNMENT PRINTING OFFICE:1978 261-250/95 1-3

DEPARTMENT OF THE NAVY

NAVAL RESEARCH LABORATORY, CODE 8404
SHOCK AND VIBRATION INFORMATION CENTER
Washington, D.C. 20375

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300.
THIRD CLASS MAIL

POSTAGE AND FEES PAID
DEPARTMENT OF THE NAVY
DoD-316

THE SHOCK AND VIBRATION DIGEST

Volume 10 No. 9 September 1978